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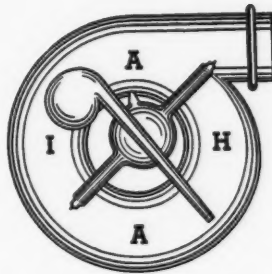
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The Mass Spectrometer as an Analytical Tool in Industrial Hygiene

G. P. HAPP, D. W. STEWART, and H. F. BROCKMYRE,
Communication No. 1341 from the Kodak Research Laboratories

FOREWORD: by JAMES H. STERNER, M.D., Associate Medical Director, Eastman Kodak Company. One of the major problems which confronts the industrial hygienist is that of resolving, analytically and toxicologically, the relative significance of individual components of a mixture of toxic agents. Particularly, when these multiple elements are so closely related chemically or physically as to defy common, practical analytical methods, we must resort to estimates or to calculations subject to many possible errors.

Many examples of the need for greater resolving power in the case of mixtures can be cited, but the instances of benzene-toluene and of mixtures of the simple chlorinated hydrocarbons will serve to emphasize the problem. The extreme hazard of benzene as compared with toluene is now generally recognized. Similarly, the discrepant toxicity of tetrachloroethane as contrasted with tetrachloroethylene, trichloroethylene, and dichloromethane is accepted. Thus far, however, there have been no really satisfactory, practical methods for accurately determining the amounts found in atmospheric mixtures.

This study by HAPP, STEWART and BROCKMYRE points a way to the solution of many of the analytical difficulties. The quantitative identification of multiple components, with the relative ease of collecting the small samples required, justifies, in my opinion, the publication of this application of mass spectrometry to industrial hygiene. In fact, so useful and so easy have we found the

method, that there is a temptation to use it for problems which could be readily solved by our more familiar techniques.

IN RECENT years the mass spectrometer has found wide application in the analysis of complex mixtures. The details of these applications have been described in the literature, and summarized in two recent reviews.^{1,2} So far as the authors are aware, however, no reports have been published of applications in the field of industrial hygiene. Work to be reported here is concerned with the analysis of low concentrations of vapors in air. A brief introduction to the general principles of mass spectrometry is included, in the hope that it will enable the industrial hygienist to evaluate our preliminary results and to suggest many additional applications in this field.

Ordinary chemical methods of analysis are usually intended to differentiate only between classes of compounds. When closely related components are present, a complete chemical analysis, if possible at all, may become so complex that it cannot be justified. In many problems of industrial importance, a variety of different alcohols, ketones, chlorinated solvents, or hydrocarbons, used in different stages of a process, may contribute to the hazard being investigated, and it becomes important to determine the amount of each individual substance present in order to identify the source and to institute proper control measures. In such situations, the mass spectrom-

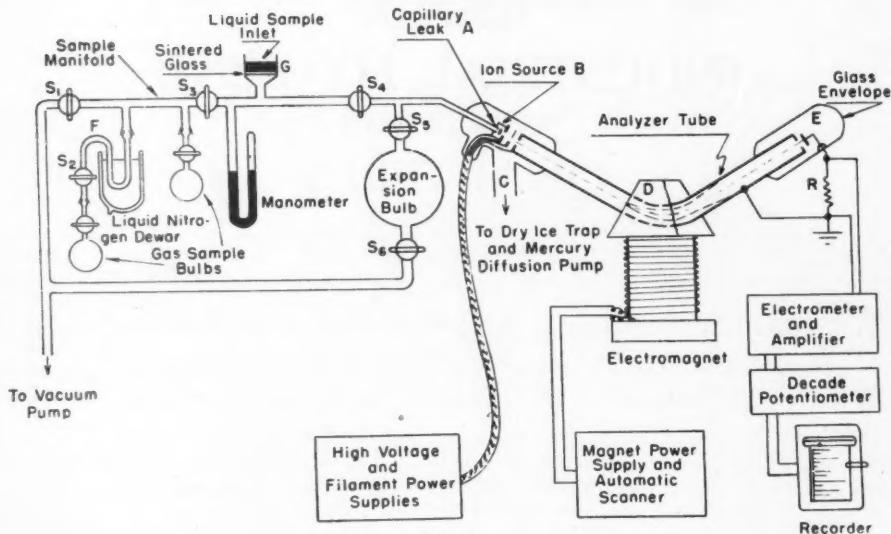


Fig. 1.
Simplified mass spectrometer

eter should be markedly superior to other methods. On a single sample, containing microgram amounts of a solvent mixture in air, concentrations can be determined for each individual component, with few limitations from interfering substances. In addition, the mass spectrometer will clearly indicate the presence of unsuspected components, and, in many cases, permit their identification and quantitative analysis. The method is rapid (20-30 minutes of instrument time per sample in the present work) and, in the mixtures and concentration ranges tested, appears to agree with results obtained by chemical methods to about $\pm 10\%$. This accuracy by no means represents the ultimate to be expected from the spectrometer itself. In many cases, this should equal or exceed the accuracy of the best chemical methods.³ Further work on sample-handling techniques is suggested in the present application.

The availability of mass spectrometers for analytical work is still somewhat limited by their high initial cost, which is about \$30,000 for a complete commercial installation of the most widely used all-purpose model. Within the last year, the usefulness of the mass spectrometer has

been increased by new and improved techniques so that installations should become common throughout the chemical as well as the petroleum industries.

Although the work reported here is limited to the analysis of vapor mixtures in air, Siri,⁴ and Dempster, Inghram, and Hess⁵ have used the mass spectrometer to analyze respired air in metabolism studies, particularly for rapidly disappearing components at low concentrations. Other applications in the field of physiology will, no doubt, suggest themselves to the reader.

In general, the method is particularly suitable where only minute amounts of sample are available, where components are so numerous or so closely related chemically that they cannot be differentiated by the usual methods, or where it is desired to take an instantaneous sample for rapid qualitative examination as a basis for further work.

Principles of Operation

THE analytical mass spectrometer is designed to separate, according to mass, gaseous ions which are formed in an evacuated system upon the admission of the sample to be analyzed. The abundance of each ionic species is then measured elec-

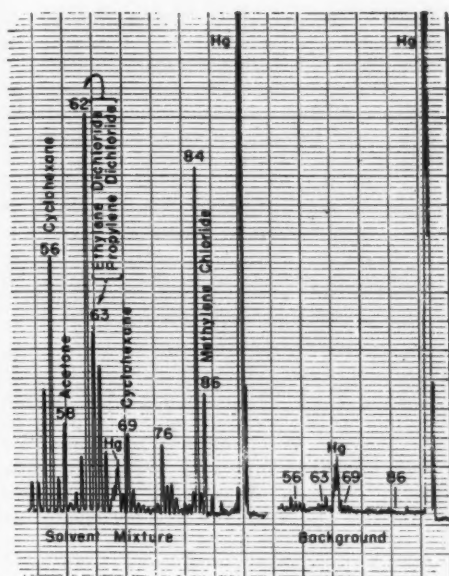


Fig. 2.

Mass spectrum of five-component solvent mixture

trically. Although special instruments have been designed to analyze relatively non-volatile samples by evaporation from an internal oven or from a hot filament, the usual instrument is suitable only for gases and for volatile compounds which can be introduced as gases. In practice, work is usually limited to substances with vapor pressures of at least a millimeter at 25°C. Less volatile materials often prove hard to pump out after the analysis is completed.

A simplified mass spectrometer is shown in Fig. 1. From the sample manifold, vapors enter the ionizing region through a fine capillary leak, A, flow through the ion source, B, where ions are formed by collisions with a stream of electrons from a hot filament, and the non-ionized portion is then continuously pumped away through C. The gaseous positive ions are accelerated and collimated by a series of slit plates successively more negative in voltage, are dispersed angularly and focused by a magnetic field, D, and are finally collected (one mass at a time) on an insulated electrode, E. The net positive charge received per unit time is a measure of the abundance of the ion being collected. The

ion current is amplified and recorded while the mass spectrum is swept past the collector, by varying either the accelerating voltage or the magnetic field strength.

A typical record of ion abundances *versus* ion mass in a sample of mixed solvents is shown in Fig. 2. The peaks occur at integral masses on the scale of atomic weights. The masses of the principal peaks and the compounds from which they are formed are identified in the figure. The scan is from mass 53 to mass 100. The peaks labeled "Hg" are produced by mercury vapor (from the diffusion pump and manometers) which has been doubly or triply ionized. A scan of the background in the instrument before the sample was admitted, shown at the right of the figure, also contains the mercury peaks and is subtracted from the spectrum of the sample before calculation.

When polyatomic molecules are admitted for analysis, the electron beam produces dissociation as well as ionization. Fragments of nearly every possible mass are formed in the process, but, for a given set of ionizing conditions, the relative abundance of each is a constant for a given substance. The absolute abundance is proportional to the amount, or pressure, of the compound in the sample system. The dissociation pattern cannot be predicted in detail from the structure of the molecule, so that the mass spectrometer must be calibrated by admitting a known quantity of the substance and recording the sizes and distribution of the peaks. When several substances are present together and are admitted to the instrument under proper conditions, the individual fragmentation patterns are additive, and the mixture spectrum can be resolved into its components, and the amount of each substance calculated.

The number of compounds which can be analyzed with the mass spectrometer is extremely large, and includes all of the common gases, and most of the common solvents and hydrocarbons of adequate volatility. To date, more than 400 reference spectra of pure compounds have been tabulated in the atlas issued by the American Petroleum Institute and the National Bureau of Standards. In mixtures where each component contributes to at least one unique

peak, the calculation of results is rapid and straightforward after the calibrating samples have been run. When the components are closely related, as in a mixture of isomers, the spectra will usually differ only in relative peak heights, and the computation may involve the solution of a set of linear simultaneous equations. Standard methods for such calculations have been developed¹ and will not be described here. Qualitative analyses depend largely upon the recognition of typical residual patterns by an experienced operator, after subtraction from the spectrum of peaks due to known components. In the case of complex mixtures, where minor components must be identified, the labor involved in making a complete qualitative analysis may become prohibitive. In the present work, only the quantitative analysis of compounds known to be present is discussed.

Experimental Details

MASS SPECTROMETER: The mass spectrometer, built in the Kodak Research Laboratory, is of the 60-degree-sector type, similar in general design to many that are described in the literature.^{6,7} The instrument, with suitable modifications, has been used for the past two years for a variety of general analytical problems in solvent analysis, as well as for isotopic assays.

The mass spectrum is scanned magnetically by an automatic motor-driven control while the peaks are recorded on a chart recorder, usually at the rate of 15 mass units per minute from mass 100 to mass 18. The rate of scan is continuously adjustable, and the range may be extended to include mass 1 and mass 200. The recording circuit includes calibrated shunts, so that multiplication factors up to 2,500 may be selected manually to magnify the smaller peaks while keeping the larger peaks on scale.

The capillary leak is a constriction at the end of the sample inlet tube inside the ion source. The over-all sample-handling manifold is shown in Fig. 1.

PREPARATION OF SYNTHETIC ATMOSPHERES: One of the two methods used for preparing synthetic atmospheres to be analyzed consisted in charging glass ampoules with weighed amounts of solvent mixtures of known composition, then breaking an am-

poule inside a 55-liter carboy which had been swept with dry air. This gave an atmosphere of known composition, except for amounts adsorbed to the glass surfaces. At the solvent concentrations used, the carboy was too small to allow the drawing of large samples necessary for comparative chemical analysis. Suitable equipment for preparing an accurately known blend of solvent and air in a dynamic system was not available.

The other method used, which permitted the drawing of samples for comparative chemical analysis, was the creation of an atmosphere of the desired solvents in a tightly enclosed laboratory (8x5x7.25 feet in size). From 25 to 100 ml. of a solvent mixture were vaporized on a hot plate in this test room, using an electric fan for circulation of the air. Sampling was usually started 20 minutes after completion of the evaporation. Solvents used in these tests included acetone, dioxane, cyclohexane, benzene, toluene, and also methylene, ethylene, and propylene dichlorides in various combinations.

SAMPLING: Several methods of atmosphere sampling for the mass spectrometer were used. The first of these, applied to acetone and dioxane vapors, and also used for chemical analysis, was absorption of the vapors in a U-tube packed with activated silica gel as a metered flow of air was aspirated through the tube. The solvents were recovered for spectrometer analysis by heating the gel in a retort at 190°C. for two hours and freezing out the solvents in a connecting U-trap cooled with liquid nitrogen, while pumping through the trap to a pressure of approximately 10^{-3} millimeter of mercury. After the run, the trap was sealed off. For some solvents, activated charcoal would be used instead of silica gel. A few samples were collected by aspirating the atmosphere directly through a liquid-nitrogen-cooled trap at the sampling location, then venting to permit the escape of liquefied oxygen before sealing. These methods are inconvenient for atmospheres containing solvents immiscible with water, since the two liquid phases must be separated, weighed, and analyzed.

Following distillation or direct trapping, a sample of the recovered aqueous mixture was withdrawn from the trap by a cali-

brated micropipette. This pipette was made by grinding to a point one end of a length of graduated thermometer tubing of known bore area. The tip of the filled pipette was immersed through the mercury seal and touched to the sintered glass disk, G, of the spectrometer sample manifold, Fig. 1, admitting a measured volume of the liquid, of the order of 0.0005 ml. This method of transferring liquid samples has been described in detail.⁸

The most convenient sampling method is to draw the atmosphere directly into evacuated bulbs. For this exploratory work, 50-ml. glass bulbs fitted with stopcocks and ground-glass joints were used, although containers with break-off seals are recommended for general use. The bulbs were evacuated in the laboratory, opened momentarily for sampling in the field, and returned to the laboratory. This method of sampling is instantaneous and represents a condition which may be quite different from the average over a period of minutes. Larger sample bulbs would extend the useful range of analysis to lower concentrations. For emergency use, a number of the sealed evacuated bulbs might be kept on hand for sampling atmospheres of interest without waiting to set up the usual absorption train.

A few bulb samples were analyzed directly by admitting a fraction of the atmosphere in the bulb to the spectrometer. However, when air is admitted directly, the largest peaks are noted at the masses characteristic of N_2 , O_2 , H_2O , argon, and CO_2 . In order to observe peaks due to contaminants, so much air must be admitted that the operation of the instrument suffers and the life of the filament may be shortened. The method would be used, however, for the determination of methane, carbon monoxide, or other substances not trapped quantitatively at the temperature of liquid nitrogen.

The most satisfactory and convenient method used for handling bulb samples will be referred to as the "air exhaustion method." In this, a bulb sample was attached to an 8-mm. U-trap, F, 4 inches deep, cooled by liquid nitrogen, as illustrated in Fig. 1. Here, the air was exhausted from the bulb while all solvents plus the carbon dioxide from the air were

collected in the trap. After five minutes of pumping, stopcocks S_1 , S_2 , S_4 , and S_6 were closed and the liquid nitrogen was removed from the trap, allowing the total solvents to thaw and completely vaporize into the sample manifold system. After two minutes, stopcock S_4 was opened, admitting the vapor to the expansion volume and the ion source.

Except for the first experiments, all the samples for the mass spectrometer were collected concurrently with those for the corresponding chemical analyses, and at the same point in the room.

CALIBRATION AND CALCULATION: For calibration of the mass spectrometer, each of the individual solvents was admitted as a liquid from the calibrated micropipette, and completely vaporized in the sample manifold. As a convenient variation of the method, a solvent mixture of known composition was frequently used as a "one-shot standard." From the observed heights of the peaks unique for a compound and from the measured quantity of liquid admitted, a calibration or sensitivity factor for each compound was obtained. For samples handled by the air exhaustion method, this factor was computed in terms of milliliters of solvent vapor (at room temperature and pressure) per chart division of peak. The volume concentration of a compound in an unknown sample was found by multiplying the height of its characteristic peak in the spectrum by the calibration factor, and dividing by the volume of the sample bulb. The sensitivity of the instrument was such that 0.0035 mg. of acetone gave a peak height of 30 chart divisions on the highest sensitivity for the acetone peak at mass 43. This quantity of acetone, in a 50-ml. bulb, would correspond to approximately 30 ppm.

Fig. 2 shows a typical spectrum of a solvent mixture containing methylene, ethylene, and propylene dichlorides, acetone, and cyclohexane. The peaks used for calculation are labeled. Ethylene dichloride and propylene dichloride were determined by solving simultaneous equations involving the peaks at masses 62 and 63.

CHEMICAL ANALYTICAL METHODS: Chemical analyses of test-room atmospheres followed established methods, where such existed. Activated silica gel was used for the collection of acetone vapors. The gel was

TABLE I.
CHEMICAL ANALYSIS OF KNOWN ACETONE-
DIOXANE MIXTURES

Sample No.	Acetone			Dioxane		
	Gm. Known	Gm. Found	Per cent Recovery	Gm. Known	Gm. Found	Per cent Recovery
1	0.00317	0.00319	100.6	0.00826	0.0075	90.8
2	0.01584	0.01595	100.7	0.0413	0.040	96.8
3	0.0317	0.0317	100.0	0.0826	0.085	102.9

TABLE II.
TEST-ROOM ATMOSPHERE ANALYSES, USING
SILICA-GEL TRAPS FOR MASS SPECTROMETER
SAMPLES

Sample No.	Component	Parts per Million Found	Mass Spectrometer	Chemical*
1	Acetone	1354		1053
	Dioxane	167		111
2	Acetone	904		1064
	Dioxane	251		234
3	Acetone	752		804
	Dioxane	373		390
4	Acetone	591		561
	Dioxane	373		458
5	Acetone	456		372
	Dioxane	322		351

*Samples for chemical analysis drawn the following day under as nearly identical conditions as possible.

transferred to a distillation flask, water was added, and distillation allowed to proceed to dryness. Acetone was then determined on aliquot portions of the distillate by the iodometric method.⁹

Methylene, ethylene, and propylene dichlorides, after collection on chloride-free activated carbon, were decomposed with liquid ammonia and metallic sodium,¹⁰ and the chloride was determined with silver nitrate. The results were calculated as moles of dichloride present.

A nitration method selected for its simplicity and convenience was employed for the determination of total aromatics.¹¹ The more elaborate methods, such as Baernstein's,¹² would

differentiate between toluene and benzene, and should be used for any further comparative work.

For the analysis of low concentrations of dioxane in the presence of acetone, the following method was devised: A distillation from silica gel (which gave quantitative adsorption of dioxane as well as acetone) was carried out as described above. On an aliquot, acetone was determined by the iodometric method. The refractive index was determined on another aliquot by the interferometer. After this, an aqueous solution containing exactly the same amount of acetone as found in the unknown was prepared. A concentrated solution of dioxane was now titrated into this until the interferometer readings agreed with those on the original. Volume changes in this titration were negligible. Table I contains data on three known samples run by this procedure.

Results

COMPARISONS of preliminary mass spectrometer and chemical analyses of atmospheres containing acetone and dioxane, using the silica-gel trap method of sampling, are given in Table II. The samples for chemical analysis were taken on a different

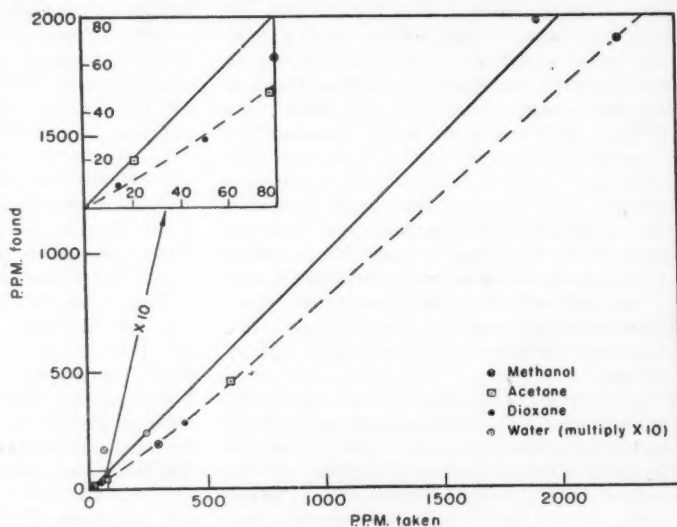


Fig. 3.
Mass spectrometer analyses of atmospheres
prepared in a glass carboy

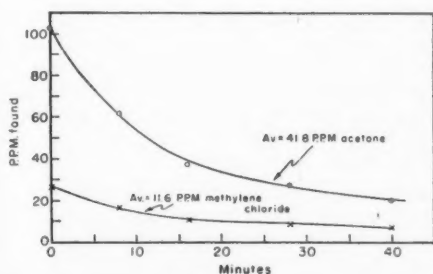


Fig. 4.

Mass spectrometer analyses of test-room atmosphere during 40-minute period

day from those for mass spectrometer analysis, but under conditions as nearly identical as possible. The differences between the two sets of results averaged 16% of the amount found by chemical analysis. While this may be satisfactory for some purposes, further comparisons were made with closer control of sampling.

Mass spectrometer analyses of atmospheres prepared in a glass carboy are shown graphically in Fig. 3. The known amounts of solvents placed in the carboy are plotted as "Parts per Million Taken," and the mass spectrometer results as "Parts per Million Found." The points for the three components, methanol, acetone, and dioxane, at concentrations above 100 ppm, all lie very close to a smooth curve shown as a broken line.

The deviation of this curve from the solid line of unit slope, representing perfect recovery, is in the direction expected from any adsorption of the solvents to the glass surfaces. Thus, at 100 ppm, the percentage error for the mass spectrometer appears to be -40%, while at a high concentration, such as 2250 ppm, where the slope of the curve is greater, the error is only -15%. The points for very high concentrations of water vapor, ten times those for the other solvents, lie much closer to the theoretical line, as might be expected, since the amount adsorbed would be but a small fraction of the whole. At 19,000 ppm, the error in the water determination is +4%.

Since it was desired to differentiate between losses due to adsorption in the carboy and losses in the sample bulbs and spectrometer due to adsorption, stopcock grease, etc., all further samples were taken in the

TABLE III.
TEST-ROOM ATMOSPHERE ANALYSES USING
AIR-EXHAUSTION METHOD FOR BULB SAMPLES

Sample No.	Component	Parts per Million Found	
		Mass Spectrometer	Chemical
1	Acetone	41.8	46.4
	Methylene chloride	11.6	13.3
2	Acetone	19.8	19.3
	Methylene chloride	36.1	39.4
3	Acetone	44.4	48.2
	Cyclohexane	30.6	*
	Methylene chloride	53.6	*
	Ethylene dichloride	43.4	*
	Propylene dichloride	36.4	*
	Total chlorinated solvents	133.4	145.5
4	Toluene	229.1	*
	Benzene	161.3	*
	Total aromatics	390.4	360.

*Not analyzed for separately.

test room, where chemical methods could be used to establish the actual composition of the atmosphere.

In Fig. 4, the concentrations of acetone and methylene chloride are plotted against the time of drawing the sample from the test room. The five bulb samples, taken during the 40-minute interval during which the sample for chemical analysis was being drawn, were handled by the air-exhaustion method for spectrometer analysis. The smooth curves for both components show the decrease in solvent concentration in the atmosphere with time, and also indicate the consistency of results which may be expected for this method. This die-away effect is probably due to absorption by the walls and contents of the room. Since the chemical results represent an integrated value over the 40-minute sampling time, the areas under the curves for the mass spectrometer data were integrated graphically. The comparable results for this sample and for three others are summarized in Table III.

Since no convenient chemical method is available for analyzing separately for methylene, ethylene, and propylene dichlorides in a mixture of all three, or for cyclohexane in such mixtures, only total chlorinated solvents and acetone were determined chemically in Sample 3.

The last sample of Table III, showing the analysis of toluene-benzene vapors in air, is of interest because of the difference between the tolerance limits of the two compounds and the ease with which the spectrometer can analyze for each in a mixture.

The presence of xylenes, ethylbenzene, chlorobenzene, and other volatile substances which might interfere with even the best chemical methods, would be revealed by the spectrometer, and their concentrations could be calculated separately.

In the seven instances where chemical and integrated mass spectrometer results can be compared in Table III, the deviations vary from 2.6 to 12.8% of the amount found chemically, with an average deviation of 8.3%. Differences in sampling procedure may account for much of the difference between chemical and mass spectrometer results. Five out of the seven mass spectrometer results are low, by an average of 9.5%, suggesting that a systematic error in handling the samples or in calibration may exist. The effect of stopcock grease and adsorption in the sample manifold may contribute to this error, but the accuracy at very low concentrations (10-20 ppm) in Table III is no worse than at 10 times this level, which would not be true if adsorption were a major effect.

For future work, the use of sample bulbs with break seals instead of stopcocks would be desirable. It would also be advantageous to calibrate the spectrometer with smaller known amounts of solvent, so that the calibration spectra would be comparable in intensity to the unknowns, or to use larger sample bulbs so as to work with larger amounts of the unknown. Other work with liquid solvent mixtures in this Laboratory has indicated that the problem of adsorption and solution in stopcock grease, even at these very low solvent con-

centrations, should not be too serious. For many purposes, the accuracy already achieved may be sufficient; in other cases, it is hoped that analysts who have access to a mass spectrometer will contribute further refinements to the method.

(Rochester, New York)

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A Practical Control Program of Health Hazards in a Metallurgical Research Laboratory

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METALLURGICAL research and development for the atomic energy program involves the utilization of "new" metals and alloys (beryllium, thorium, uranium and others). The problems of processing and fabricating these materials are considerable. Unlike most metallurgical research, the work is complicated further by the radiological and chemical toxicity hazards associated with the handling of metallic materials that have properties which make them well suited for atomic energy development.

In the planning and construction of a modern metallurgical laboratory, the research facilities must be integrated well and complete health protection must be provided for the working personnel. The recently completed facilities of the Metallurgical Division of the Oak Ridge National Laboratory have been described recently by Jetter and Stansbury.¹

The potential health problems encountered in a metallurgical research and development program for the atomic energy field are diversified and can be divided into radiation hazards and chemical toxicity hazards, i.e., exposure to beryllium. The hazards of radiation are lessened somewhat by the fact that "hot" materials are not handled in operations productive of particulate matter.

These materials may be handled in bulk form and the operator is furnished with adequate personalized protection. Moderately radioactive metals and alloys may be fabricated or processed with equipment which is productive of dust; however, the severity of these hazards should be no greater than that encountered on handling highly toxic non-radioactive materials. The fabrication and processing of these give rise to particulate contamination in the form of dust or fume, depending upon the operation involved.

This presentation will confine itself to the health and sanitary facilities of the new laboratory and will emphasize the ventilation control which was provided for the protection of the working personnel. Existing health protection measures developed in two stages and consisted of the following phases: (1) The laboratory layout of equipment and facilities, together with the general ventilation design (both exhaust and supply) and sanitary provisions were considered in the initial planning which was followed by installation by the contractor; (2) The specific hood design and installation at the equipment to be used in the processing and handling of toxic metals and alloys was carried out by interested groups within the laboratory. The results of these two phases of planning will be clarified by photographs and sketches. The housekeeping and sanitary facilities will be touched upon in the latter paragraphs.

No attempt has been made to evaluate the effectiveness of individual control hoods. An extensive air sampling program has been initiated; however, the findings to date are inconclusive. It is hoped that the air data will be accumulated and presented at a later date.

General Ventilation

THE metallurgical laboratory is contained within a quonset construction (103 ft. x 220 ft). The floor plan is shown in Fig. 1, where the type of activity carried on within each room is indicated. The building is divided into five separate and relatively independent ventilating, heating, and air conditioning zones, and each zone is represented by various shades of crosshatching on the floor plan. Table 1 shows the design volumes of air handled by each system and the intended function of each system. For example, Zone No. 1 includes the metallography and chemistry sections that are maintained at constant humidity and temperature the year round to meet certain requirements that are demanded in the

1. JETTER, L. K., and STANSBURY, E. E.: Metallurgical Laboratory at Oak Ridge. *Metal Progress*, 56:187 (August) 1949.

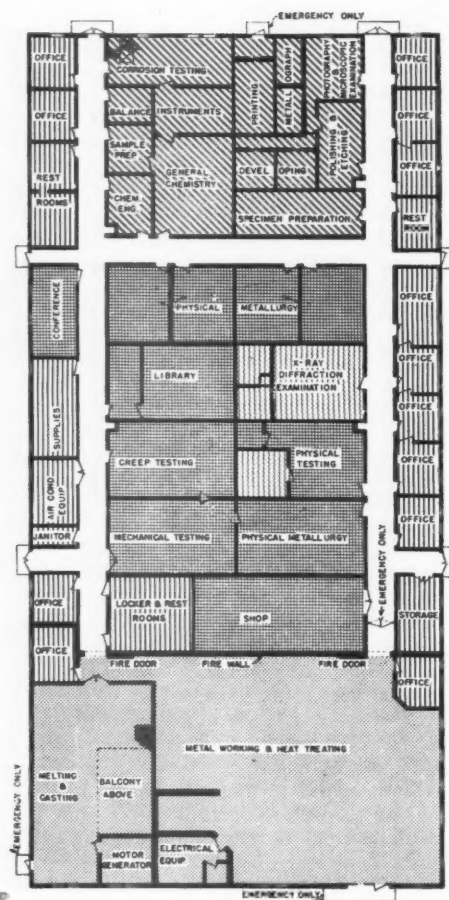


Fig. 1.

Floor plan of laboratory for Metallurgical Division of Oak Ridge National Laboratory. Shaded regions indicate various general ventilation and air conditioning zones. See Table I for key

operation of precision equipment and storage of photographic material. This system handles 6015 cfm (design value) of which about 40% is recirculated.

Zone No. 3 covers the offices that are supplied with outdoor air properly tempered in the heating season. Zone No. 4 indicates

*Contaminated area—Signifies a working area that is potentially capable of becoming contaminated by the nature of the activities carried on within that area. In this discussion the expression contaminable and contaminated are synonymous.

TABLE I.
GENERAL VENTILATING SYSTEMS

Legend ¹	Zone No.	Total Air cfm ²	Outdoor Air cfm	Function
	1	6015	3500	Air conditioned. Year around temperature and humidity control.
	2	10310	4850	Air conditioned. Year around temperature control.
	3	5860	5860	Ventilation. General supply. Tempered in winter.
	4	35000 14000	— —	General exhaust vent. Local exhaust vent.
	5	1230	230	Air conditioned. Year around temperature and humidity control.

¹See Fig. 1.²cfm—cubic feet per minute

the main contaminable area* which is located at the east end of the building and is maintained under a negative pressure to prevent the dispersion of potentially contaminated air to other sections of the building. The two hallways running lengthwise through the building serve as large air supply ducts supplying the contaminated area with air discharged from the offices and other areas. The exhaust air volume of 35,000 cfm for Zone No. 4 is merely an estimate based upon the air handling catalogue performance of propeller fans located in the roof of the quonset. The total volume of air removed by the dust collecting system in Zone No. 4 is 14,000 cfm.

Any one, or a combination of roof exhaust units, can be operated depending upon circumstances. If several dust producing operations are in progress, the fans may be turned on to insure the flow of air into the contaminated zone from other zones in the building. During the summer months, these fans are operated frequently to take up heat gains within the rooms. Undoubtedly, the full exhaust ventilation load of the contaminated zone could effect the proper functioning of the other ventilation systems. Experience to date has been quite good with the operation of the various ventilating systems shown in Fig. 1. For anyone entering or leaving the contaminated area, it is quite obvious that the flow of air is into this area as it was planned. Unit heaters are suspended from the ceiling (ceiling height is 17 to 20 feet in this section) to take care of the heating load during the cold season.

Local Ventilation

SINCE most of the dust producing operations were located in one end of the building in the initial planning, the main exhaust ventilating system was constructed to take care of these potentially dangerous operations. The main system was extended, also, to take care of chemical fume hoods and minor dust producing operations in other sections of the building. Several independent exhaust systems, serving one or two hoods, were installed in isolated portions of the building where it was not practicable to extend the main system.

(a) *Piping:* In research and development work, equipment is utilized intermittently and some operations and processes are performed infrequently, which is in direct contrast to production operations and facilities. In all cases, ventilation control, where deemed necessary, must be available, irrespective of the degree of utilization of equipment or facilities. In the design of local exhaust ventilation for research activities, cognizance must be given also to the somewhat indeterminate nature of the work; hence, systems should be over-de-

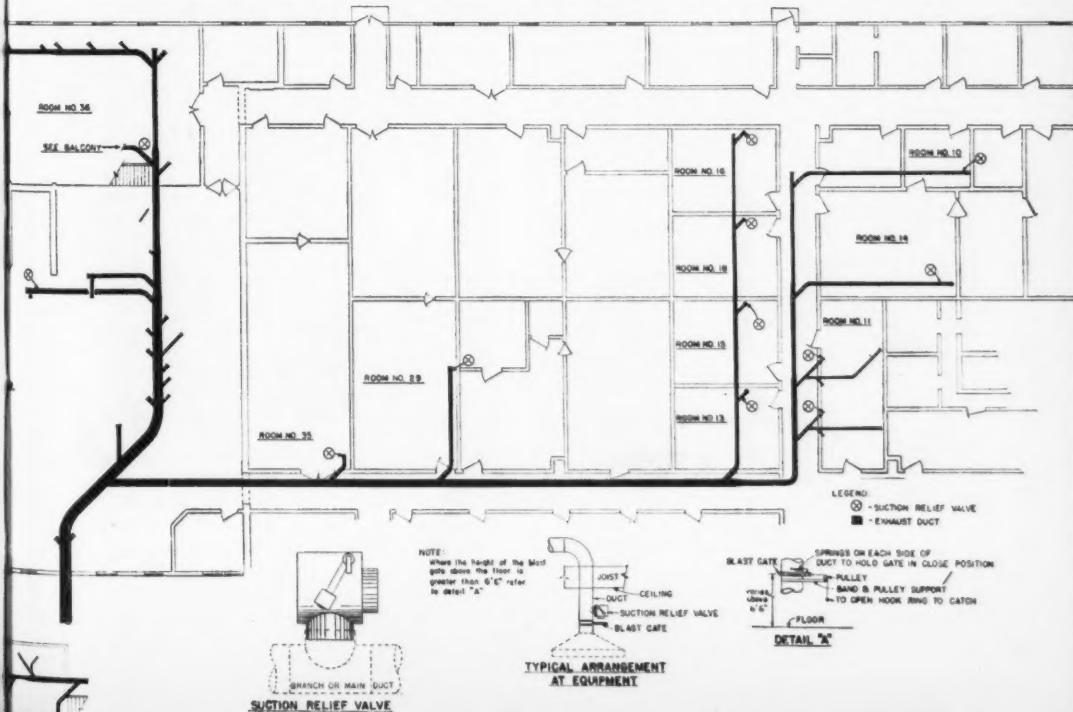
signed to afford the desired degree of flexibility to take care of the expansion which most naturally attends progress in research and development.

The use of the balanced system for local exhaust ventilation design is ruled out in research laboratories. Blast gates or dampers are employed to insure adequate air flow at a hood where the equipment is in use; since no ventilation control is needed at equipment not in operation. The ventilation contractor at the Metallurgy Laboratory designed a system based upon the use of blast gates and suction relief valves. The design rate of air flow was adjusted by means of a diversity factor determined by the simultaneous operation of various pieces of equipment which were to be installed at a later date. In order to take care of this variable load factor and maintain constant velocity in ducts, suction relief valves were provided in the original exhaust system at the remote ends of the duct work. The location of these valves is shown in Fig. 2.

The layout of the piping of the main exhaust system may be seen in Fig. 2.

Figs. 2 and 3.

Piping layout of main dust collecting system. Suction relief valves are shown on the ventilation plan with suction relief valve shown below. Arrangement of valve and blast gate at hood over equipment



Certain sections of the floor plan are omitted.

Branch ducts were terminated by the vender and capped, in some cases, except that piping was connected to standard designed chemical fume hoods located in various rooms (Fig. 2). Piping was installed into other laboratories for future use. The relief valves were installed along with blast gates at these hoods and at duct ends in these laboratory rooms. The arrangement of relief valve and blast gates is demonstrated in Fig. 3. When the hood is not in use, the blast gate is closed mechanically and the relief valve opens automatically, hence the air is by-passed through the relief valve. These valves were to be adjusted manually in the field for maintenance of the desired duct velocity, which was designed originally at 4000 feet per minute.

Hoods were designed and installed by laboratory personnel at equipment productive of dust following completion of the building and installation of the equipment. Branch ducts were run from the stubs to

the hoods and manually or mechanically (spring tension) operated blast gates were inserted in each branch duct connected to the hood. In actual operation, the blast gate is opened when the equipment is in use, and closed when the equipment is not in use.

(b) *Hoods*: When handling highly hazardous material, i.e., beryllium, ventilation control should be extremely effective to achieve the desired low levels of environmental contamination. In recent months, medical authorities have suggested threshold limits for beryllium contamination that approach zero concentration. Ideally, we can accomplish most effective ventilation control by enclosing the dust generating sources and ventilating. In many instances it is neither feasible nor desirable to enclose an operation. In such cases, we must resort to semi- or non-enclosing hoods, with or without baffling, and provide high control velocities at the source of dust production.

With the Laboratory hood design problems several factors influenced the thinking on ventilation control. Hoods were con-

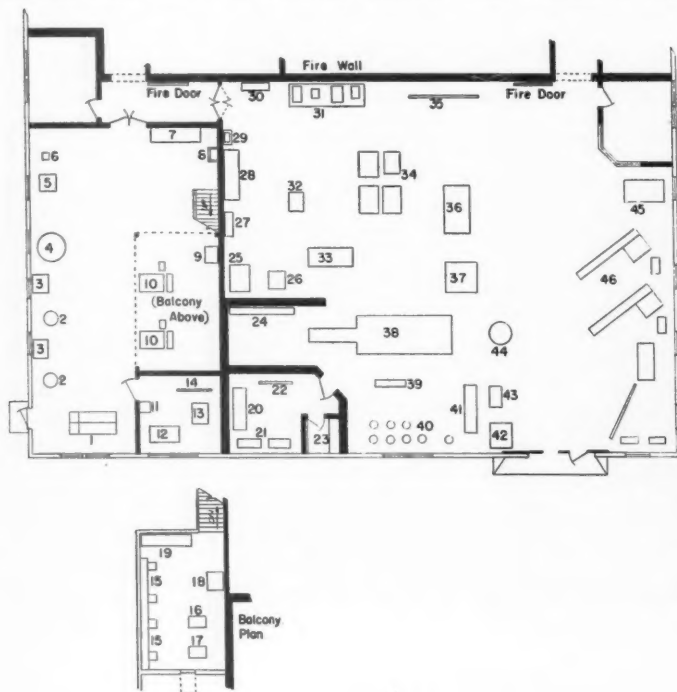


Fig. 4.

Melting, Casting, Metal Working and Heat Treating Laboratories. Legend: 2—Resistance melting furnaces (hood); 3—Casting benches (hood); 4—Resistance melting furnace (hood); 6—Small induction melting furnace (hood); 7—Work bench (hood); 9—Mold shakeout (hood); 15—Vacuum induction melting furnaces (hood); 16—Open induction melting furnaces (hood); 32—Rotary swaging machine (hood); 33—Electro-pneumatic forging hammer (hood); 34—Resistance heating furnaces (hood); 36—Rolling mill (hood); 37—High temperature resistance furnace (hood); 38—Extrusion press (hood); 45—Wet abrasive cut-off machine (hood)

sidered as an essential and integral part of dust producing equipment and processes, and had to be installed before such equipment could be used. Consequently, time was an important factor in completing the ventilation installation. In most research work, the equipment must be dismantled easily and readily, which means that hoods should not be too complex. Hood design should be simplified in the early stages of planning and improved, if indicated, through experience gained from usage of equipment. Furthermore, hoods should be flexible to some degree, either in manipulation during actual use, or in removal during disassembly of equipment.

After the hood design had been approved by the interested laboratory groups, the hoods were installed. It was our plan to study the operation carefully, by taking many air samples and by improving the efficacy of the hoods where indicated. Unfortunately, the equipment has not been utilized so fully as was expected, so there has been little or no change made on initial designs.

A floor plan of the contaminated area, located in the east end of the laboratory

building, and the general layout of equipment are shown in Fig. 4. Numerals are used to assist in the identification of the

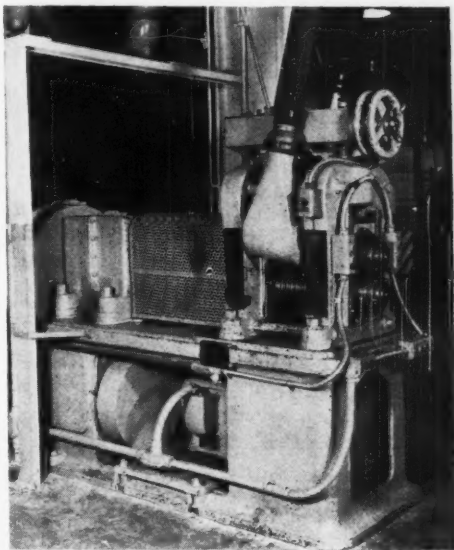


Fig. 6.
Rolling mill with flexible local ventilation

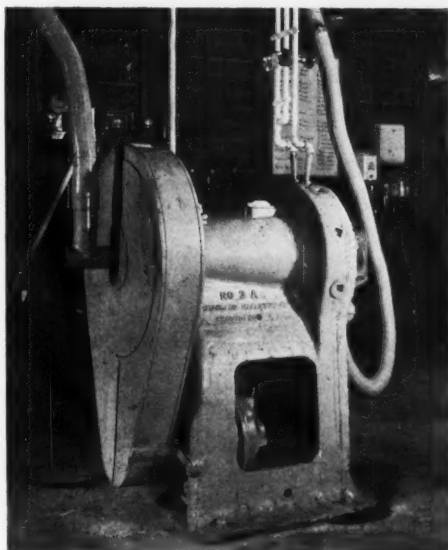


Fig. 5.
Rotary swaging machine with flexible local ventilation

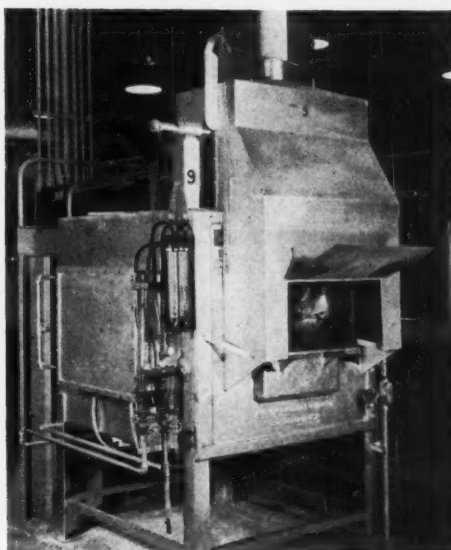


Fig. 7.
High temperature resistance furnace with exhaust hood

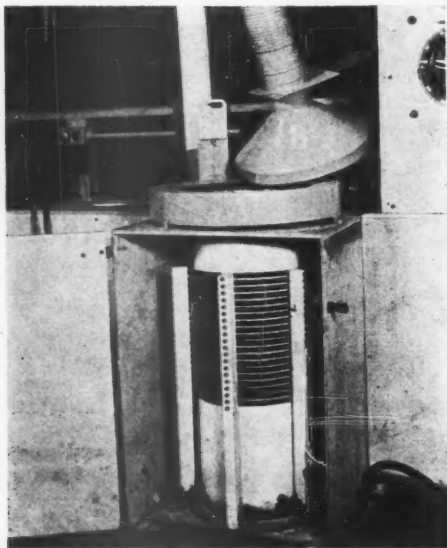


Fig. 8.
Vacuum induction melting furnace. (A) Rim type local exhaust hood and (B) conical exhaust hood (flexible piping)

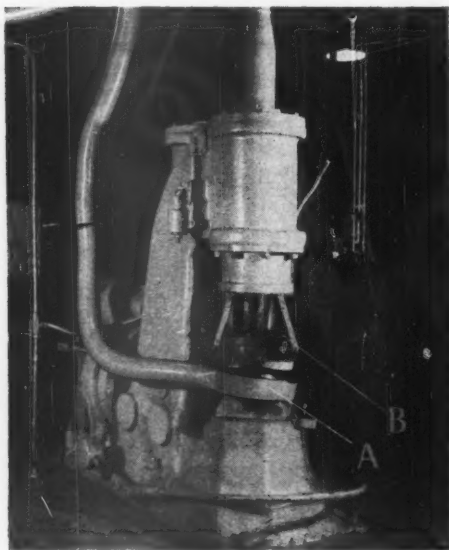


Fig. 9.
Electro-pneumatic forging hammer with rim type hood (A) and plexiglass baffles (B) is shown above

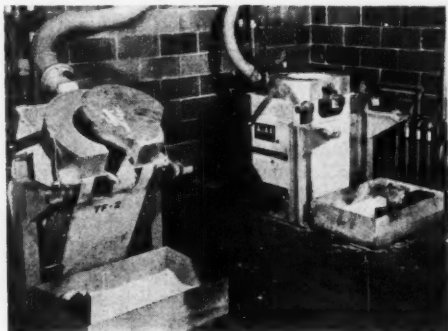


Fig. 10.
Open induction melting furnaces with rim type hood. Ball and socket joint and flexible metal piping allow hood to move with furnace

equipment. Figs. 5 through 13 show the initial hood designs installed at various pieces of equipment potentially productive of particulate contamination.

(c) *Dust Collector*: The contaminated air from the local exhaust ventilating system is passed through a series of air filters and then is discharged through a 40-foot steel stack to the outside atmosphere. The over-all filtering unit consists of two in-

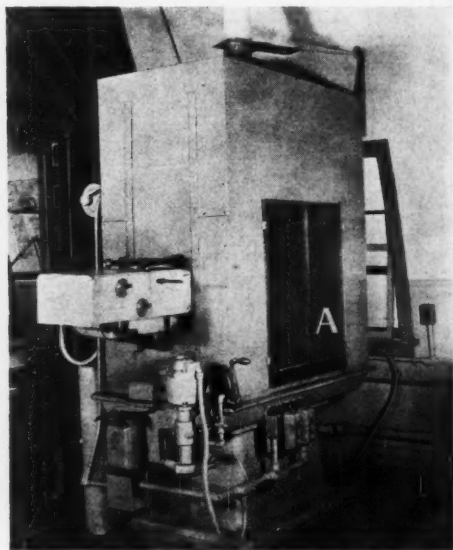


Fig. 11.
Wet abrasive cutoff machine with ventilated enclosure. Plastic doors (A) are closed when the machine is in operation

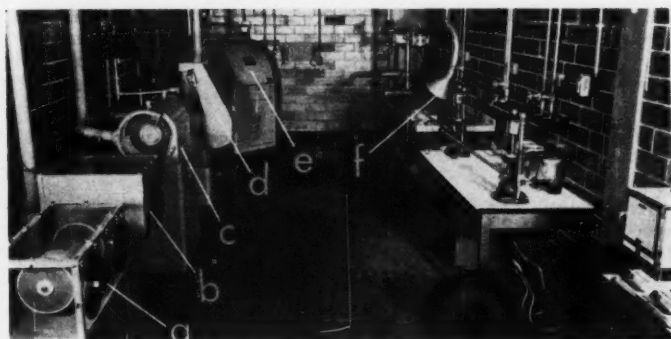


Fig. 12.

Specimen preparation room. (a) Disc grinder (enclosed and ventilated); (b) Horizontal belt surfacer (enclosed and ventilated); (c) Wet powder grinder (partially enclosed and ventilated); (d) Belt surfacer (enclosed and ventilated); (e) Wet abrasive cutoff machine (enclosed and ventilated); (f) Flexible exhaust hood for work bench operations

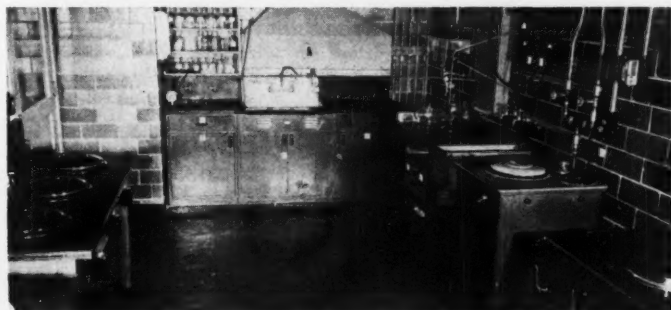


Fig. 13.

Polishing and etching room. Adjustable horizontal slot hoods (A and B) connected to separate exhausters

dividual collecting units arranged in series. The entire assembly is shown in Fig. 14, with part of the stack visible in the right background.

The first unit consists of four cyclonic separators arranged in parallel. The cyclones were installed to remove the bulk of the dust load, the coarse material, thereby lengthening the useful cycle of the dispensable filters. The discharge from the cyclones is passed through the second filtering unit which consists of a bank of highly efficient, disposable-type filters suitably arranged in a filter house. The filters have an efficiency of 99+ % in removing particles in the range of 0.3μ (microns) and less. The pressure drop across the overall filtering unit is about 6 in. WG at the present

time. The resistance through the cyclones is about 3 in. and through the filter bank 3 in. The pressure drop across the replaceable filter bank increases as the filters become plugged. An inclined manometer is connected over the filter bank and the pressure drop is recorded weekly in an effort to determine the increase in filter resistance. The entire system has been in operation over a year with no appreciable increase in filter resistance. The dust load to date has been exceptionally light.

The disposal of collected contaminable materials is of paramount importance. Cyclone separators have a storage hopper and the hoppers are inspected and emptied, as indicated. A steel receptacle, (A) shown in Fig. 14, was

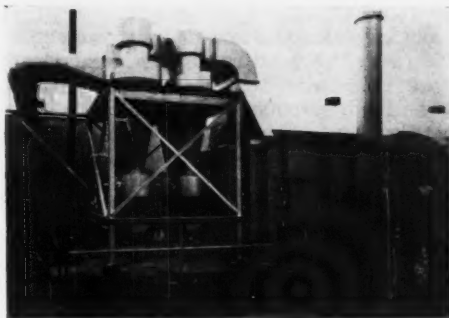


Fig. 14.

Dust collecting system showing cyclonic collectors arranged in parallel, filter house, exhausters and steel stack. (A) Disposable steel receptacle for dust

constructed for disposition of the dust collected in the storage hoppers. The disposal of the replaceable filters is more complicated. In another similar filter installation, the dust is fixed in the disposable filter by spraying the exposed faces with lacquer. The filters, after spraying, are removed, packaged, and transported, by truck, to the burial ground where they are buried. In this way, the problems of contamination are minimized. The persons removing the filters must be provided with protective clothing and respiratory devices.

(d) *Fan*: The air is moved through the ventilating system by a General Blower Company No. 90 Steel Plate Exhauster which is directly connected to a 150 HP motor running at 1175 RPM. The fan is connected directly to the discharge of the filter house through a transition piece that can be seen in Fig. 14. The discharge from the exhauster is into a 40-foot steel stack, 32 in. in diameter. The filter and fan motor installation is on a concrete slab foundation outside the quonset construction.

The system is handling 17,500 cfm of air at a static pressure of 18.5 in. W.G. The duct system characteristics may vary depending on the utilization of dust producing equipment and processes. The above results were obtained under normal conditions.

The fan output is 55 HP. Brake horsepower into the fan is about 190 HP. Fan efficiency is about 25% under present operating conditions.

Sanitation

LOCKER, WASH AND LUNCH ROOM FACILITIES

(a): The location of the locker and wash room with reference to the various areas in the Metallurgy Building is shown in Fig. 1. Additional facilities are available for office personnel throughout the building and will be mentioned only at this time. The main locker room, Fig. 15, contains lockers and wash (lavatory and shower) and toilet facilities. Interior construction consists of glazed tile walls and a concrete floor covered with asphalt tile. The floor is provided with proper drains to facilitate regular washing down.

The contaminated area (designated Zone No. 4 in Fig. 1) and the locker room are juxtaposed. Regularly assigned employees

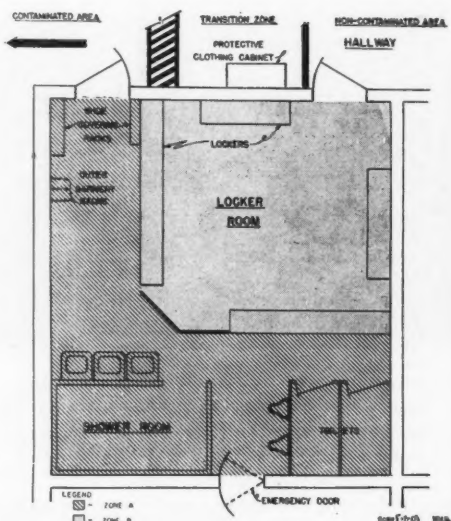


Fig. 15.

Floor plan of main locker and wash room

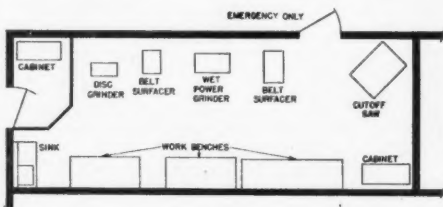


Fig. 16.

Floor plan of specimen preparation room

enter and leave the contaminated area by way of the locker room through doors which lead directly into the hallway. In the locker room, the employee changes his clothes at the beginning and end of his working shift; and washes and showers as instructed.

Two sets of lockers are assigned each employee to preclude cross contamination of work clothes with street clothes. An ample number of towels, soap and foot protectors are furnished to the employee.

A radiation detection counter is provided in the locker room to check for personal radiation contamination. A counter is placed in the hallway adjoining the Melting and Casting Area to detect radiation contamination of employees, equipment, tools, etc., leaving the contaminated area.

Emergency doors are located in the contaminated areas as indicated in Fig. 1 and Fig. 12. An emergency door connects the locker room with the adjoining shop. As the name implies, these doors are to be used only in time of emergency. All travel of both equipment and personnel is scheduled through one portal for each contaminated area which leads into the non-contaminated area. These portals demarcate the contamination areas where rules are established for the wearing of protective clothing, eating, drinking, etc.

A room in a non-contaminated zone has been set aside for use as the lunch room. Tables and chairs are provided for the personnel, and all employees in the building may eat in this lunch room. Drinking and eating are prohibited in the contaminated areas at all times. Personnel working in a contaminated zone must change outer garments, remove foot coverings, and wash thoroughly before entering the lunch room. The lunch room is monitored daily for radiation contamination.

b. Protective Clothing: Personnel, who are regularly assigned to work in the contaminated area, are furnished with work clothing which includes trousers, shirts, undergarments, shoes and stockings. The clothes are laundered, as indicated, by the company and issued to the employee for his use. The regularly assigned employee may wear a smock over these clothes or may wear coveralls in lieu of the above mentioned clothes. He may or may not wear shoe coverings; however, he must remove his shoe coverings or shoes upon entering Zone A, Fig. 15, before using the facilities provided in Zone A. Also to enter Zone B, or any non-contaminated section from the contaminated areas, all employees must remove their outer garments. Suitable racks are provided for shoe coverings and outer garments as shown in Fig. 15. Hence, it is more expedient for the employee to wear a smock over his work clothes or coveralls since these articles of apparel are removed easily and quickly.

Personnel who may work part time in contaminated areas are instructed to wear smocks or coveralls and shoe coverings. This group includes technical and trade personnel as well as visitors. Smocks, coveralls, caps and shoe coverings are available

in a suitably designed cabinet shown in Fig. 15. Any person entering the contaminated zone from the non-contaminated area passes through a transition zone where he must don the required protective clothes before proceeding. A broad yellow line clearly defines the boundary of the contaminated zone in the east end of the building. Conversely, any employee leaving the contaminated area must remove his clothing either in Zone A shown in Fig. 15 or in the hallway on racks located to the left of the broad stripe likewise shown in Fig. 15. A similar arrangement is provided in the specimen preparation room, the plan of which is presented in Fig. 12. A line is shown which defines the contaminated area in Fig. 12.

Employees and visitors may enter and leave contaminated zones at will during the shift; however, they must put on or take off the outer garment and shoe coverings that are provided for their use. All protective clothing is laundered by the company.

c. Housekeeping: Partition walls in the contaminated area are constructed of glazed tile. The inside surface of the exterior walls is constructed of plaster board and floors in this area are of concrete. Adequate drains are provided for washing down the floors.

Portable industrial vacuum cleaners are provided throughout the contaminated areas for cleaning purposes. Technicians are instructed to clean up their work area upon completion of their job or at the end of the shift.

Contaminated areas are mopped and washed down with soap and water at least twice a week or more frequently if indicated. A heavy blotting paper is provided to be used on floors and work benches; however, this paper is used mostly to absorb radioactive wastes. The paper is placed in suitably covered receptacles for disposal.

Steel service tables were designed and constructed to be used in conjunction with charging and discharging the electric furnaces located in the Metal Working Area. A metal lip is fastened to the table to catch any chips or large particles which ordinarily would fall to the floor when moving material in or out of the furnace. The tables can be moved about with the aid of casters.

Several work benches are provided with flexible local exhaust hoods. These hoods are used when the operator is handling hazardous materials which may give rise to the emission of particulate matter. Work benches are cleaned at the completion of the job with vacuum cleaners for no dry sweeping is permitted in contaminated areas.

Chemical fume hoods are provided in laboratory areas throughout the building, and chemical experiments are conducted within a hood. Also, other equipment and experimental test runs which may give rise to contamination are placed within the confines of a ventilated fume hood enclosure. In this manner, contamination is isolated within the hood. This arrangement protects the experimenter and also reduces cross contamination within or among the laboratory rooms.

Each employee is charged directly with the responsibility of maintaining good housekeeping.

Caution signs are displayed in fume hoods and contaminated zones signifying that beryllium work is being conducted. Technical personnel are not permitted to work with contaminants in their offices, nor are they permitted to carry contaminating materials from area to area if there is the remotest probability of promoting surface or airborne contamination. Solid beryllium specimens and the like may be handled freely since there is no chance of generating air borne contamination or spreading surface contamination.

Floors of laboratories, offices, and hallways are covered with asphalt tile. These areas are swept daily and mopped at least once a week. Filter paper smears are taken to check radiation contamination of work benches, hoods, floors, etc. This work is done routinely by health physics monitors. Filter paper smears are taken to check working surfaces and floors for beryllium contamination and are analyzed spectrographically for total beryllium content. No surface contamination levels have been established for beryllium. If smear results appear to be "excessive," additional housekeeping measures are put into effect until surface contamination levels are reduced. These surface checks are not correlative with air findings but they do serve to check

the effectiveness of housekeeping procedures.

d. *Personnel Protective Devices*: Employees working in the designated contaminated areas are provided with respiratory protective devices. These devices are recommended for use where the exposure may be high and brief. It is not our aim to substitute a respiratory program for positive engineering control. However, it is not feasible nor economical always to provide control for short duration, intermittent exposures. The wearing of respirators is based upon previous excessively high air findings or a supervisor's instruction. An approved dust and fume type filter is used in all respirators. Each individual is requested to care for his own respirator.

The wearing of respirators is never a desirable feature of any contaminant control program. At best, a respirator is uncomfortable, but more important is the fact that respirators are worn haphazardly. Supervision must be alerted constantly to enforce the use of respirators where it is deemed necessary. Individual technicians appreciate the protection offered by respirators, and have been very cooperative in wearing such devices. However, it is the little job which only takes a few minutes that provokes much of the negligence.

It is not within the province of this discussion to describe the safety program. Suffice it to say that the Laboratory personnel is provided with all such safety protective devices as are indicated by their job risk. The employees cooperate wholeheartedly in utilizing whatever safeguards that are furnished for their comfort and safety.

Summary

THE handling of toxic and radioactive materials in Metallurgical Research for atomic energy development presents many potential environmental health problems. Research facilities in a modern metallurgical laboratory for atomic energy must be integrated with engineering measures and personnel protective procedures for the control of such health hazards.

The mechanics of setting up an environmental control program for toxic dusts and fumes are discussed. The essential features of such a program are:

1. Dust producing equipment and processes were isolated to minimize air-borne and surface contamination and reduce the incidence of exposure.

2. General mechanical ventilation zones were planned with non-contaminable areas under positive pressure and contaminable areas under negative pressure.

3. A local ventilation system was installed with an ample air cleaning system.

4. Local exhaust hoods were incorporated at all operations potentially capable of producing particulate matter.

5. Good housekeeping practices under close scrutiny of health physics monitors were initiated and maintained.

6. A rigid personnel protective clothing program was set up.

7. Ample sanitary and locker room facilities were installed to encourage habits of good personal hygiene.

It is not possible to evaluate fully the effectiveness of a well-planned and coordinated environmental health protection program; however, a program of this scope has a stimulating effect upon the morale of the employees. No program of health protection is complete unless it is coordinated with an air analysis program and integrated with a medical control program including physical examinations and clinical and laboratory tests.

Opportunity for Visiting Lecturers in Industrial Hygiene

THE COMMITTEE on International Exchange of Persons of the Conference Board of Associated Research Councils announces an award afforded for a visiting lecturer in Industrial Hygiene for the academic year, 1951-52, at Queen's University, Belfast, Ireland. The award is intended to cover all essential expenses, including maintenance, travel within the country, and round-trip transportation. Supplemental cost of living allowances for accompanying dependents will be added on request.

To apply as a visiting lecturer, the applicant must have had teaching experience in an institute of higher learning. Application forms are to be obtained from the Executive Secretary of the Conference Board at 2101 Constitution Avenue, Washington, 25, D.C., and returned by October 15, 1950.

Fundamentals of Polarographic Analysis

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THE polarographic method as an analytical tool has been known for almost 30 years but its adoption has not been as widespread as might have been hoped considering its versatility and sensitivity. It can be fairly said that the average analytical chemist has not embraced the method with startling alacrity despite the fact that numerous applications in diverse areas of analytical interest are available including iron and steel analysis, white metal analysis, control of electroplating solutions, and analysis and research in petroleum products and biological fluids. It is the purpose of this paper to outline fundamental polarographic theory, describe basic instrumentation and methods, and illustrate polarographic application to some characteristic problems in the hope of increasing general familiarity with the method, especially in the field of industrial hygiene.

Polarography was discovered about 1922 by Prof. Jaroslav Heyrovsky of the Charles University of Prague.¹ Its discovery serves as another example of how major advances in chemistry frequently result from pursuing side roads rather than the main highway. In this case Heyrovsky had been assigned the problem of studying the anomalies in the electrocapillary curve of mercury by Prof. Kucera, but the interesting current-voltage curves he obtained whereby he was able to relate magnitude of current with concentration of an ionic species led to this new analytical method and world renown for its discoverer. Since that time the field has expanded almost exponentially and has associated with it such well known names as Hohn² in Germany, Semerano³ in Italy and Shikata in Japan. Prominent in the field in this country are Kolthoff⁴ and his group at the University of Minnesota, Lingane, a former Kolthoff student now at Harvard, Laitinen, also a Kolthoff student now at Illinois, Meloche and Adkins at Wisconsin and Müller at New York University, to name but a few.

In essence, the polarographic method of analysis is a special form of electrolysis

involving the use of a dropping mercury electrode which has the property of exactly reproducing electrode phenomena at successive drops and further has a very high hydrogen over-voltage allowing determination of alkali metals. In this unique type of electrolysis there are obtained current-voltage curves from which it is possible to qualitatively identify an electro-oxidizable or reducible species and, simultaneously, to quantitatively determine its concentration. (In all fairness to the method, it must be that its potentialities as a qualitative tool have been somewhat over-stressed and as a result the uninitiated have been slightly dismayed on realizing that it is not a panacea for all analytical ills.) Ordinarily, the anode consists of a large quiet pool of mercury or a standard reference half-cell such as a calomel electrode, while the cathode consists of fine slow drops of mercury exuding from a capillary orifice. The optimum concentration range is from 10^{-5} to 10^{-2} molar, but less than microgram quantities may be determined with the use of special techniques involving volumes as small as 0.1 ml.

The basic requirements of polarographic instrumentation are really quite simple and,

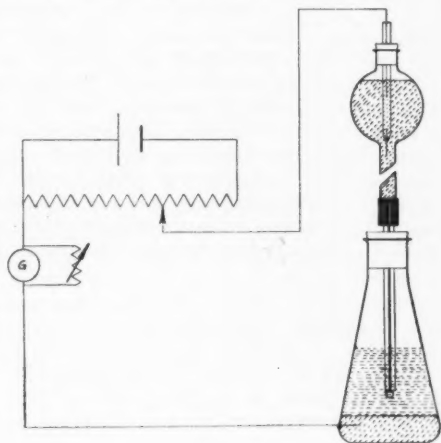


Fig. 1.

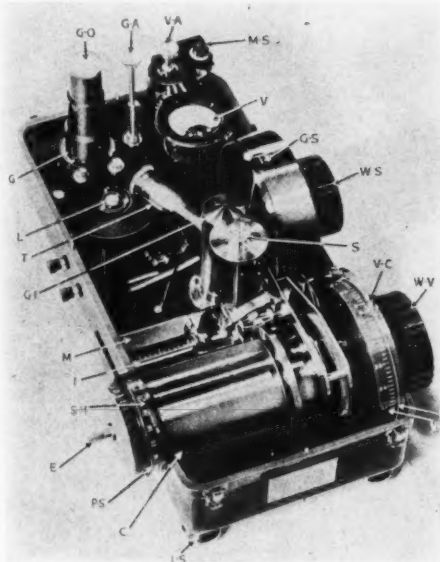


Fig. 2.
Heyrovsky-Njedly Micro-Polarograph
(Made in Prague)

as shown in Fig. 1, consist of a source of EMF across a voltage divider for application of a gradually increasing potential to the electrolysis cell, which in this case consists of a pool of mercury as the anode while the cathode is a reservoir of mercury connected to a capillary outlet. The capillary outlet may be drawn from thermometer tubing but more satisfactory performance is obtained through the use of so-called "marine barometer" tubing. Usually the diameter of the orifice is about 0.05 mm, the drop time of the mercury is in the range of two to six seconds and the maximum diameter of the drops at the instant of breaking is about 0.5 mm. The current flowing during the electrolysis is measured by a galvanometer in series with the cell and usually has a sensitivity of the order of 10^{-9} amperes per mm. To vary the sensitivity over the rather wide concentration ranges encountered, the galvanometer is equipped with an Ayrton shunt. Currents may also be measured by replacing the galvanometer with a precision resistor and measuring its potential drop as a function of current flow. Both of these methods of current measurement are available in com-

mercial polarographs with accessories for either visual observation or automatic recording. A versatile manual-visual circuit of research caliber has been described by Kolthoff and Lingane.⁵

One of the first commercially available polarographs is shown in Fig. 2. This model is the Heyrovsky-Njedly Micro-Polarograph, manufactured in Prague prior to World War II. It evolved from a more versatile research model as particularly suited to routine determinations. As such it has obvious limitations in studies in fundamental electrode phenomena and reaction mechanisms but is well suited to general analytical measurements. In this unit, a gradually increasing potential from 0 to 4 volts is applied to the electrolysis cell by means of a governor-controlled clockwork motor which drives a helical resistor mounted on a fiber drum. A sensitive galvanometer equipped with an Ayrton shunt is used to measure the current. The polarogram or current-voltage curve is photographically recorded on a cylindrical drum carrying ordinary bromide paper and mounted axially with the slide-wire drum.

Fig. 3 shows the first American model of the Heyrovsky polarograph, developed by E. H. Sargent and Company after importation of the Czech model was stopped by the advent of the war. This unit is essentially

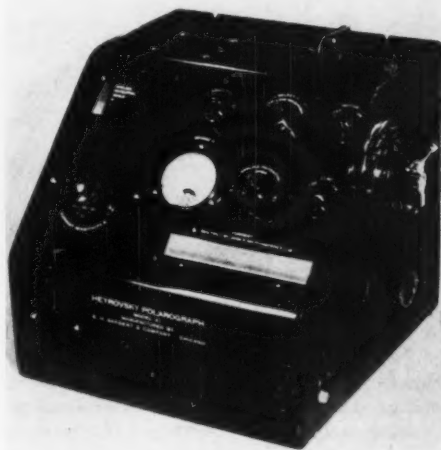


Fig. 3.
First American model of Heyrovsky Polarograph
(E. H. Sargent and Company)



Fig. 4.
Model XII Polarograph (E. H. Sargent and Company)



Fig. 5.
Manual Polarograph, Model III (E. H. Sargent and Company)

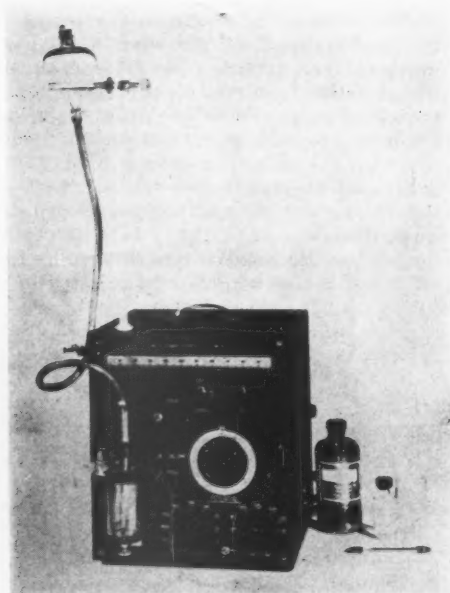


Fig. 6.
Manual Polarograph-Electropode (Fisher Scientific Company)

the same as the European model but embodies American principles of design and construction. Fig. 4 shows a later model which employs an improved circuit for compensating or masking undesired wave forms. Figs. 5 and 6 show the manually

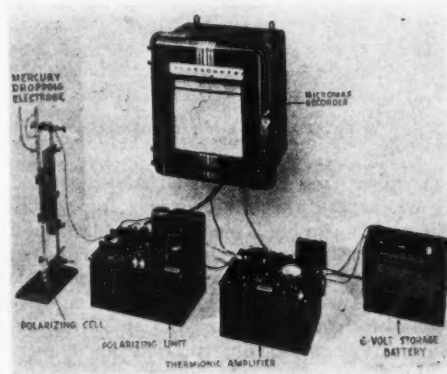


Fig. 7.
Electro-Chemograph (Leeds and Northrup Company)

operated polarographs manufactured by E. H. Sargent and Company and Fisher Scientific Company respectively. In both of these units, increasing potentials are applied by hand and the galvanometer deflections are noted visually for subsequent plotting of the current-voltage curve. An instrument which employs the principle of measuring currents by determining the equivalent IR drop across a precision resistor in series with cell and records that equivalent current on a Micromax recorder is the Electro-chemograph manufactured by Leeds and Northrup Company, Fig. 7. This instrument has recently been re-



Fig. 8.
Model XX Polarograph (E. H. Sargent and Company)



Fig. 9.
Model XXI Polarograph (E. H. Sargent and Company)

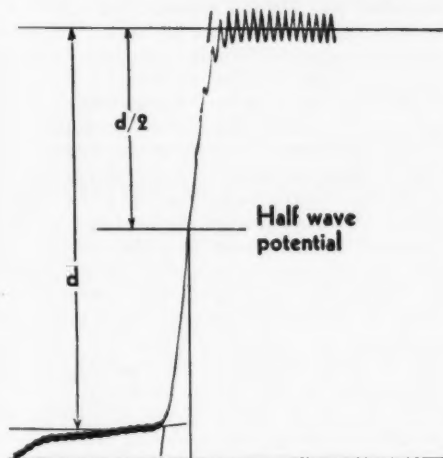


Fig. 10.

designed and now employs a Speedomax recorder in place of the Micromax. Figs. 8 and 9 show the latest potentiometric recording models manufactured by E. H. Sargent and Company. These units also measure current through a dropping resistor but recording is made with a Brown Electronik recorder. In addition, compensation circuits are provided and condenser damping ar-

rangements are available for reducing current oscillations resulting from the growth and fall of the cathodic mercury drops.

A typical polarogram of an air-free solution of 0.001 molar lead nitrate in 0.1 molar potassium nitrate is shown in Fig. 10. This current-voltage is an automatic photographic plot of increasing negative potentials along the abscissa against resultant currents along the ordinate. Initially, only a very small current, the condenser current, results from the application of increasing negative potentials until continuous electrolysis starts at the decomposition potential of about -0.4 volts vs. the saturated calomel electrode. The electrode reactions during the electrolysis involve the deposition of lead in the cathode drops as a very dilute amalgam, while, at the anode, mercury dissolves in equivalent quantity to form mercurous nitrate. It is of importance to note that the current does not increase indefinitely with increasing voltage, but rather becomes constant and independent of further increase in voltage. This constant or limiting current is directly proportional to the concentration of material being deposited at the cathode and it is this very

proportionality which makes quantitative polarography possible.

The proportionality between concentration and magnitude of limiting current may be explained by closer inspection of the electrolytic process. At the start of electrolysis, the concentration of depositing material becomes depleted at the surface of the cathode and is replaced only by diffusion from the body of the solution. The rate of diffusion is directly proportional to the difference in concentration between that at the surface of the cathode and that in the body of the solution. Very soon, the concentration at the cathode surface becomes so small that the difference between the concentrations at the cathode surface and in the body of the solution becomes practically equal to the concentration of the solution. At this stage, the rate of diffusion becomes constant and hence the quantity of material discharged at the cathode also becomes constant; the current flowing is thus also constant and proportional to the concentration of depositing material in the body of the solution. Since this limiting current is controlled by the diffusion process it has become known as the diffusion current.

Strict proportionality of the diffusion current to concentration is achieved only under two specific conditions—(a) an extreme state of concentration polarization which results when one electrode is very small and the concentration of reducible substance not too large, and (b) elimination of electrical forces which might supply ions to the cathode by ordinary electrical migration. It is from this condition of concentration polarization that the term polarography arises. Electrical migration may be reduced to negligible minimum by having the electrolysis occur in the presence of large excess (50 to 100 times) of an indifferent electrolyte which may be defined as an electrolyte having a decomposition potential much more negative than the substance being studied. The most common indifferent electrolytes are the alkali metal salts and the tetra-alkyl substituted ammonium hydroxides or halides.

The geometry of measuring the diffusion current as the difference between the residual current and the total wave height is shown in Fig. 10. Formerly it was customary to record the current in terms of

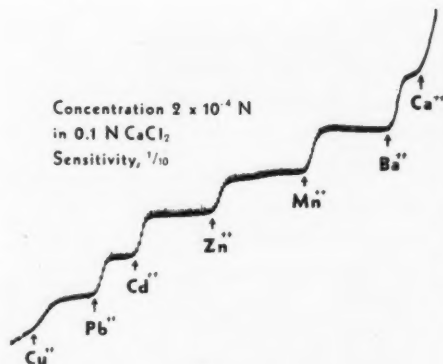


Fig. 11.

millimeters but present day practice makes use of the more fundamental unit of microamperes which is the product of mm of wave height and the galvanometer sensitivity in amperes per mm. Diffusion currents range from as low as a few hundredths of a microampere to as high as 50 microamperes but seldom exceed this value.

Fig. 10 also shows the method of measuring the potential which identifies the ion being deposited. The voltage at half the diffusion current is the characterizing voltage and is called the half-wave potential.⁶ Other methods of denoting the decomposition voltage include ordinary extrapolation of the vertically sloping portion of the curve to the abscissa, measurement of the voltage value of the intercept of a 45° tangent to the curve, the voltage value of the point of maximum curvature, and the voltage value at which an increase of 10 millivolts produces an increase of 1.9×10^{-9} amperes. All of these alternative measures of measuring the decomposition potential are dependent on concentration, galvanometer sensitivity, drop time and the rate of flow of the mercury. In contrast, the half-wave potential is independent of these variables and is thus a true characterizing voltage. Qualitative identification of a series of ions by means of their half-wave potentials is illustrated in Fig. 11 where the respective voltages are as follows: Cu, +0.02; Pb, -0.41; Cd, -0.59; Zn, -1.01; Mn, -1.51; Ba, -1.90; Ca, -2.2. It should be noted that this polarogram is really academic since all the ions are present in the same concentration. In actual practice this favor-

able condition is seldom met and the real status ranges from one where a relatively positive element is present in great excess over more negative elements to the exactly opposite status where a more negative element is in excess over the positive elements. The later case lends itself directly to solu-

composition voltages for inorganic ions and organic compounds respectively.

Organic polarographic reductions depend on reaction with hydrogen which accounts for the dependence on pH as shown in the table. In general, organic compounds except unconjugated acids containing structures normally regarded as reducible by hydrogen will lend themselves to polarographic measurement. However, organic polarography is not as simple and straightforward as the inorganic field since the reactions are frequently not reversible and experimental conditions must be sharply defined.

While measurement of the diffusion current alone is all that is necessary in routine concentration measurements, other related variables must be considered when studying electrode reactions or mechanisms of reaction. Ilkovic⁷ was the first to derive from theoretical considerations the equation which now bears his name and which relates diffusion current to all the other variables and fixed factors which account for its magnitude. The equation was subsequently derived more rigorously by MacGillavry and Rideal⁸ but their derivation reduces to the Ilkovic form essentially. In the Ilkovic equation

$$I = 0.63 n F C D^{1/2} m^{2/3} t^{1/6}$$

"n" is the number of electrons involved in the deposition, "F" is the Faraday, "C" is the concentration, "D" is the diffusion coefficient of the reacting ion, "m" is the mass of mercury flowing per unit time, and "t" is the drop time.

Concentration calibrations may be made as shown in Figs. 12 and 13. Fig. 12 shows a series of polarographic waves for cadmium ion in concentrations from 0.0002 to 0.002 normal in 0.2 N potassium chloride as the indifferent electrolyte. Fig. 13 shows the data of Fig. 12 plotted as wave height in mm. against concentration. Routine con-

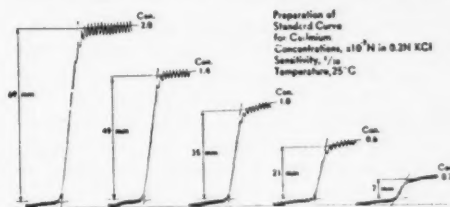


Fig. 12.

TABLE I.
TYPICAL HALF-WAVE POTENTIALS OF
METALLIC IONS

Element	E vs. SCE*	Remarks
Al	-1.75	In 0.05 N potassium chloride
Bi	-0.01	In 1 N nitric acid
Cd	-0.59	In 1 N nitrate or sulfate
Cr	-0.88	As chromous ion in 0.1 N potassium chloride
Co	-1.20	As cobaltous ion in 0.1 N ammonium chloride
Cu	+0.02	In 0.1 N potassium nitrate
Fe	0.00	As ferric ion in potassium chloride
Fe	-1.30	As ferrous ion in 0.1 potassium chloride
Pb	-0.41	In 1 N nitrate
Mn	-1.51	As manganous ion in 1 N potassium chloride
Ni	-1.10	In 1 N potassium chloride
O	-0.10	In 0.1 N chloride—reduction to peroxide
K	-2.13	In 0.1 tetra methyl ammonium hydroxide
Sn	-0.35	As stannous ion in 2 N perchloric acid
Zn	-1.01	In 1 N potassium nitrate

*Saturated calomel electrode.

TABLE II.
TANGENT POTENTIALS OF TYPICAL ORGANIC
COMPOUNDS
Conc. X 10⁻³ Normal

Compound	pH	E
Acetaldehyde	3.9	-1.61
"	7.0	-1.83
Acetone	2.0	-1.28
Benzaldehyde	3.9	-1.26
Butyraldehyde	7.0	-1.70
Dinitrobenzene, o	3.9	-0.15, -0.31
" m	3.9	-0.20, -0.33
" p	3.9	-0.18, -0.35
Dinitrophenol 2, 4, 1	3.9	-0.13, -0.31
" 2, 5, 1	3.9	-0.19
" 2, 6, 1	3.9	-0.12, -0.23
Fumaric acid	1.0	-0.54
"	3.9	-1.70
Maleic acid	1.0	-0.54
"	7.0	-1.90
Nitro-aniline, o	1.0	-0.19
" m	1.0	-0.11
" p	1.0	-0.18
Oxalic acid	1.0	-1.20
Vitamin C	7.0	-1.80

tion by polarographic means but the former requires manipulation either chemically or electrically as will be illustrated later. Tables I and II list some representative de-

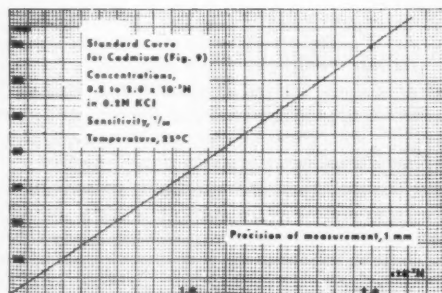


Fig. 13.

centration measurements of an unknown determined under similar conditions may be read directly from such a calibration curve but its utility fails if experimental conditions change. Thus, temperatures should be reasonably uniform since the average temperature coefficient of the diffusion current is about 1% per degree C. Similarly, if it should become necessary to change a capillary, a new calibration curve would be required. The drudgery of preparation of a series of calibration curves may be avoided where a wide variety of measurements is in progress by using the method of internal calibration which involves simply the addition of a known volume of known concentration of the ion in question to a known volume of the unknown and running a second polarogram. From the known concentrations and the corresponding wave heights, the unknown concentration can then be calculated as follows:

$$\frac{m}{h_1} = \frac{m + a}{h_2}$$

where "m" is the unknown mass, "a" is the added mass, "h₁" is the wave height of the unknown, "h₂" is the wave height of the unknown plus the known, and "v" and "v₁" are the volumes of unknown and known respectively.

To secure well-defined and easily measured polarograms, two experimental conditions must be observed. The first of these is concerned with interference of oxygen dissolved in solution. Dissolved oxygen is reduced at the dropping mercury electrode as shown in Fig. 14. Here the upper curve results from the polarographic electrolysis of 0.001 M potassium chloride saturated

with air ($2.5 \times 10^{-4}M$), and is characteristic of oxygen containing solutions. Such wave forms would obviously interfere with the wave forms due to reducible ions in that voltage range, necessitating the removal of dissolved oxygen. Fortunately, oxygen is relatively easily removed by mechanical means involving the bubbling of hydrogen or nitrogen through the test solution for a period of two to 30 minutes depending on the sensitivity. Occasionally, chemical reducing agents such as sulfites may be used but such use is not generally advised since they or their oxidation products may produce interferences. Fig. 14 also shows the results of such bubbling with hydrogen, the middle curve showing the relative oxygen level after a 30-second bubbling and the lower curve indicating complete removal after a further 2-minute bubbling.

The second experimental condition which requires attention is concerned with distortion of wave forms by the superimposition of undesirable maxima. Referring to the upper wave of Fig. 15, it is seen that a large well-defined maximum is present. In the case of oxygen, this maximum is characteristic and strictly proportional to the oxygen concentration. Metallic ions also display maxima though they are not necessarily proportional to the concentration of ion present and they may or may not appear depending on the peculiarities of solution composition. Obviously, such maxima would tend to distort wave forms and preclude quantitative measurements, so all efforts



Fig. 14.



Fig. 15.

must be made to forestall their formation and appearance. In most cases maxima may be suppressed merely by the addition of minute quantities of surface active agents such as gelatine, methyl cellulose or some of the organic dyes such as fuchsin, methyl red etc. The suppression of the oxygen is shown in Fig. 15 where the lower curve shows the two characteristic oxygen waves after the addition of two drops of 0.01% gelatine solution. The more positive of the two waves results from the reduction of oxygen to hydrogen peroxide while the second is the result of the further reduction of hydrogen peroxide to water. The peroxide wave is also characteristic of organic peroxides and can be used for their determination, both qualitative and quantitative.

Thus far only the most rudimentary considerations have been outlined. To illustrate the feasibility of a polarographic approach to an analytical problem a specific example will be considered. The analysis of a zinc-base die-casting alloy for copper, lead and cadmium serves as a particularly satisfactory illustration. In this particular case, copper was present to the extent of about 0.2%, while lead and cadmium were each present in the amount of 0.004% each. Iron and tin were present in trace amounts but quantitative information on them was not desired. As the first step, reference to a table of half-wave potentials must be had to determine whether a sufficient voltage separation exists to allow the formation of discrete wave forms. A voltage separation of about 0.2 volt is generally considered adequate. Examination of a table of half-wave potentials reveals that iron and copper deposit at about the same voltage in the neighborhood of 0.0 volt vs. SCE. This would result in a single wave form for the two ions. However, the iron was present as a trace constituent so that its contribution to the total wave would be negligible and might be disregarded. Lead and cadmium have half-wave potentials of about 0.4 and 0.6 volts respectively which allows adequate difference for the formation of separate waves. The presence of tin which has a deposition potential close to that of lead might have complicated affairs except and also would offer a negligible contribution to the total lead wave. However, tin



Fig. 16.

was eliminated as an interference in the course of preparing the sample for analysis.

HAVING demonstrated that the polarographic method was feasible from the voltage standpoint, it was necessary to consider the relative sensitivity relationships. An experienced polarographer can estimate and evaluate sensitivity requirements very easily, but the typical analysis of this alloy will serve to illustrate the nature of such experience. The sample was prepared by dissolving a 5 gram portion in concentrated nitric acid, boiling to expel the oxides of nitrogen, coagulation of precipitated metastannic acid by further boiling with distilled water and removal of the metastannic acid by centrifuging. After washing with several small volumes of hot water to release adsorbed copper, lead, and cadmium, the combined filtrates were made up to 100 ml., the excess of nitric acid serving as the indifferent electrolyte. A 5 ml. portion was transferred to an electrolysis cell and polarographed at a sensitivity of 1/200 after the addition of 0.1 ml of 0.1% acid fuchsin solution to suppress any copper maximum. The wave at the left in Fig. 16 shows the relative amounts of the three metals, the first large wave being copper and the two barely discernable waves on the copper plateau being lead and cadmium. To determine the copper present, the method of internal calibration was used. To the solution just run, 0.5 ml. of a copper nitrate solution exactly 12 times as strong as the original was added and the polarogram rerun as shown to the right in Fig. 16. From the proportionality previously shown, the copper content was readily calculated as 0.193%. Having determined the copper, it might appear that the lead and cadmium could be measured merely by extending the sensitivity of the galvanometer to increase



Fig. 17.

their wave heights to suitably measureable size. As previously noted, this procedure is confined to cases where the ion in lower concentration is the more electro-positive, so that in this instance increasing the sensitivity would result in proportional increase in the copper wave and the lead and cadmium waves would disappear off the polarogram. The difficulty may be solved by either electrical or chemical means. Electrically, a current equal in magnitude but opposite in sign could be fed into the circuit to balance out the copper diffusion current; this is the compensation technique for which provision is made in the modern polarographs. It is only fair to mention that frequently the resultant wave residue is so grossly distorted that accurate measurement is almost impossible. Chemical means are more satisfactory and involve precipitation reactions, complexing reactions in which the ion in question is tied up in a compound which is not reducible, or change in oxidation state. In this problem hydroxylamine was used to reduce the copper to the cuprous state from which it is not reducible in acid solution. All that was necessary was to add a few crystals of hydroxylamine hydrochloride to the same sample in the electrolysis cell and stir them into solution with the hydrogen used to remove oxygen from solution. Galvanometer sensitivity was extended to 1/20 and the polarograms rerun as shown in Fig. 17. The lower wave at the left represents the

lead and the upper the cadmium. Both waves were calibrated by the method of internal calibration with the results shown in the middle for lead and at the right for cadmium; percentage of lead, 0.0039; percentage of cadmium, 0.0036. The results of this method of analysis checked within 0.1% with those obtained spectrographically. The total time required was just less than 30 minutes.

The treatment, brief as it is, should suffice to demonstrate the general applicability of the polarographic method. Its use in the field of industrial hygiene has not been too widespread though its versatility and sensitivity should attract the interest of all analysts in this area of activity. In industrial hygiene its use seems to have been restricted to the routine determination of lead in urine but all the more familiar metallic hazards in all biological fluids and in atmospheric samples should be capable of ready determination. Well established analytical procedures need be modified but little to lend themselves to a polarographic approach. The application to organic materials will probably require the development of suitable procedures but the method should prove invaluable in many cases where present methods do not allow ready distinction between closely similar compounds.

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Industrial Hygiene Codes

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WITH a subject as ambiguous as "Industrial Hygiene Codes," it is necessary to start with some qualifications. For the purposes of this discussion the term "code" will be limited to its more official connotation,—that of a compilation of principles, rules, and regulations promulgated by an official agency to aid in the interpretation of a law. As an example, in New York State, the Board of Standards and Appeals, an agency of the Department of Labor, has adopted by authority of the Labor Law a wide variety of rules relating to industrial operations, each of which is designated as a Code. These rules have the force of law, and enable the appropriate official agency to investigate or to take legal action against anyone not conforming to them in practice.

Because the term "code" has been used as synonymous with "standard," it is desirable to differentiate these concepts in their present significance in industrial hygiene. Particularly, with respect to the idea of an acceptable concentration of a toxic agent, there has developed a definite distinction in their meanings. "Standard" has come to mean a criterion established by recognized technical authority with general consent, a guide to good practice, and free from the legal implication of "code." It may prescribe certain "minimum" values, a level of conditions below which it is unwise or even dangerous to go, or it may designate a set of criteria which are recognized as optimum practice—an objective distinctly above that which generally is being done, or even likely to be done for some time by a major segment of the industry.

With the general purposes of codes developed by governmental agencies for the enforcing of certain minimal criteria of industrial practice there can be little disagreement. The many examples, more commonly inadvertent but occasionally deliber-

ate, of flagrant violation of safe operating principles are ample justification for official controls. As a corollary agreement, with the establishment of the basic labor law, the increasing complexity of industry requires amplification of the general law by specific regulations. These are often of value in protecting industry from capricious and arbitrary decisions of enforcing agencies, as well as being more efficient in forcing compliance through a direct and clearly defined mechanism.

There is a definite, continuing trend in the various states and larger cities, to establish codes relating to an increasing number of industrial activities. With the crystallizing of certain industrial hygiene concepts, and an expanding need for more complex industrial environmental controls, it is natural that these ideas should be considered for incorporation in official regulations. It is at this point, however, that disagreement, even among those individuals who are regarded as well versed in industrial hygiene matters, becomes evident. The disagreement pertains to the manner in which the information should be related to the regulations, and to the specific values, particularly those designated as "maximum allowable concentration" values.

In several of the states, specific maximum allowable concentration values have been incorporated in the appropriate codes for the control of hazardous substances. In others, the limits serve merely as a guide to the enforcing agency. It is reported that in one state the legislature considered the enactment of a law containing a table of such limits, with all of the implied rigidity of such a procedure, but fortunately the bill did not pass. The recent action of the State of California may serve to illustrate one pattern.

Within the past year, as a part of the general Industry Safety Orders, specific "maximum acceptable concentration" values for 146 dusts, fumes, and vapors were adopted. These values largely correspond with those recommended by the Committee

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on Threshold Limits of the American Conference of Governmental Industrial Hygienists. In the publication of these orders, the limiting concentrations are given as an appendix prefaced with a good statement of the qualifications and limitations of such figures. However, reference to earlier paragraphs leaves little doubt but that these specific values can be used for enforcement purposes. In the section on the "Control of Ventilation" it is stated, "Whenever harmful dusts, fumes, mists, vapors or gases exist or are produced in the course of employment, in quantities giving rise to *harmful exposure* of employees . . . such hazards shall be controlled by the application of general ventilation, local exhaust ventilation or other effective means such as pressure ventilation . . ." A *harmful exposure* is defined as "exposure to dusts, fumes, mists, vapors, or gases of such duration and such concentration as to produce effects herein defined as harmful. *Concentrations which are considered to be the maximum acceptable for various substances are listed in Appendix A.*" Thus, a number of specific substances are assigned legal limiting values. The situation with respect to harmful physical agents, specifically, ionizing radiations, is similar excepting that it is stated, "The Division of Industrial Safety plans to hold hearings on revision of the (values) annually."

The Code Relating to the Removal of Dust, Gases, and Fumes adopted by New York State in 1931 illustrates, when compared with the recent California orders, the considerable change in approach which has occurred. Although this rule is still operative in New York, modification, including a table of specific limiting values (containing only 52 items) was developed but not adopted in 1942, and is currently being considered for revision. The principle of defining a specific limit for a particular hazardous substance has since been incorporated in other Codes pertaining to special industries. The relatively indefinite criterion of the 1931 Code was, "All machinery creating dust or impurities in quantities *tending to injure the health of employees shall be equipped with proper hoods and pipes connected to an exhaust fan . . . to remove such dusts or impurities.*" It is obvious that the designation of specific limits would

considerably clarify the job of the enforcement agency.

Since the question of "maximum allowable concentration" values is such an important factor in considering the virtues and defects of industrial hygiene codes regulating exposures to hazardous agents, it is proper to discuss the current status of this perennially disputed subject. The concept of a concentration of a particular hazardous material which will not prove harmful (or in varying degree of acceptance, uncomfortable) even though an individual is exposed daily and for an indefinite period, is to most industrial hygienists a very useful one. The discrepancy in opinion, however, as to the possible validity of such a value—and especially to the significance of a given set of data establishing a limit for a particular substance, is considerable.

There has been a change from the relatively ready acceptance of a proposed maximum allowable concentration of a few years ago to the present mood of cautious scrutiny. We have lived long enough with some of our earlier conclusions to see them modified, and we are less certain of our other values. In addition, we have been justifiably alarmed at the rigid authority which a value acquires with repetition (even though uncritical) and the threat of even greater immutability by incorporation in legal regulations.

The activities of the organizations which have been most widely recognized in the establishing of standards have contributed to the confusion. On the one hand, the limited output of the American Standards Association Committee on Allowable Concentrations of Toxic Dusts and Gases implied an increasing doubt as to the availability of adequate data for other than a few materials. On the other, the Committee on Threshold Limits of the American Conference of Governmental Industrial Hygienists issued annual reports containing values on well over a hundred items, and including certain materials of which, it was generally felt, there was sufficient information only for a "questimate." A careful examination of the purposes of both groups in developing standards shows that their activities are far from irreconcilable, that it may well be desirable to have both of them continue

setting and publishing standards. It is important, however, where there is a significant difference in their results, to document the studies upon which their conclusions are based and, in addition, so far as possible, the criteria by which the decisions were made. It is inevitable that there will be differences, and occasionally, really appreciable differences, but it should be made clear that in the majority of instances these are a matter of interpretation, and not based upon different sets of factual data.

There is now a serious apprehension that the various state agencies will increasingly incorporate in codes the values approved by the American Conference of Governmental Industrial Hygienists, in spite of the openly expressed opinion of some members of that Threshold Limits Committee warning against such a practice. On the one side, is the obvious responsibility and need of the enforcing agency for specific criteria. On the other, is the frequent disagreement by hygienists employed in industry with the selected limit and their reluctance to accept values determined under conditions in which they could have no part. It will be pointed out that state codes are adopted only after public hearings, but it is doubtful that the committee formed to draw up or revise the code will have the technical competence for the best judgment on a widely diversified list of substances, or that such hearings are the best means for weighing the highly technical material upon which limits must be based. It would be much more desirable to add authority to a given standard by having it originate from a common technical body, representing all phases of industrial hygiene activity. The American Standards Committee on Allowable Concentrations of Toxic Dusts and Gases at one time seemed to have these qualifications, but the limited results, as judged by the number of standards adopted, have raised serious doubts as to whether its past performance will meet the needs of the situation.

The varying degree of validity of standards presents one of the most difficult problems. A promising suggestion has been repeatedly made that standards be established in classes or categories, according to the amount of available evidence for fixing a given level. Where there was a

considerable amount of pertinent data, sufficient agreement could be expected to permit the establishment of a reasonably fixed value. While there will be continued objection from some individuals to the use of such information in codes, much of the present criticism of this action would be avoided. Intermediate and lower categories would include those values with lesser validity, and these would be used merely as guides. While all values, as at present, would be subject to revision as additional information was developed, the intermediate and lower level figures would be given a limited tenure, requiring regular and systematic review.

Codes can be characterized as to the manner in which they function. In one type, the "definitive" code, the engineering specifications are described in great detail, requiring compliance as to gauge of metal, size of ducts, velocity or volume of air flow, etc., of the equipment or device for controlling the hazardous condition. Enforcing agencies emphasize that these are matters which can be checked by less technically trained inspectors. In addition, guidance as to an adequate design and construction is essential, particularly in the smaller plants, if competent engineering skill is not available. These arguments are countered by industry which complains of the restriction imposed, of the difficulties encountered in substituting newer, and perhaps more economical and more effective controls for the methods dictated in the code.

A second type of code is the "performance" code. Here the emphasis is on the end result, which is described and defined—and the method for achieving it is left, in great part, to industry. The difficulties from the enforcement view are the paucity of criteria for defining the acceptable environment, and the necessity of greater technical competence in personnel investigating the industrial conditions. Industry, however, has greater freedom as to methods for controlling the hazard.

If it is agreed that codes are necessary to secure safe and healthful conditions under certain circumstances (and the author subscribes to the viewpoint), one or the other, or a combination of the two, of the above types of code must be employed. The

definitive code may appear to be the easier to enforce—and perhaps the easier to comply with—for many standard operations and processes. It lacks, however, the directness and versatility of the "performance" approach in dealing with the actual problem, the hazardous condition. With the increasing ability to define the desired end and to evaluate the actual circumstance of exposure, there is a trend toward the adoption of performance codes. The California Safety Orders are of this type. In addition, the suggested model or standard code recently prepared by a committee of the American Conference of Governmental Industrial Hygienists was expressly a "performance" type. In New York, a recent revision of the Product Finishing Code, to supplant and extend the regulations originally covering product spray painting, is a good example of compromise between the two principles, although no specific concentrations are given.

With this background, let us consider the probable directions of Industrial Hygiene Code making, and what can be done to assure reasonable, valid, and workable regulations. In the first place, it is likely that our increasingly complex society and technology will require more rules and regulations. The present trend is toward the adoption of performance codes, although enthusiastic and perhaps premature acceptance as mandatory of too many unverified "permissible concentration" values may react to slow the development.

A major need is a constantly expanding set of criteria which will be broadly accepted and which will define safe, healthful, and reasonably comfortable working conditions. Values may be developed for a number of purposes, but one set or class must describe minimal standards—levels of performance below which it is unsafe and unwise to go. These standards should be set by mutual agreement, in an organization where the greatest competence and experience of all phases of industrial hygiene activity can be represented. Such values as meet a certain degree of validity can be properly designated, and might be incorporated in mandatory regulations, if in the opinion of enforcing agencies that action seemed desirable. For materials about which information was less complete

and less accurate, tentative values can be assigned and these used as guides while further data is collected.

It is unlikely that poorly substantiated values included as mandatory features of a code would be sustained in a legal action unless there was clearly defined objective evidence of injury. The inclusion of such less well verified limits, and attempts to enforce them, must cast doubt on the validity of even the more securely established values. To meet the objections raised by enforcement agencies, that smaller units of industry will be penalized because of the absence of definitive data on engineering controls, such information could be incorporated in the codes as suggested techniques, permissive but not mandatory. At present, in New York, where such engineering details are in the code, the mechanism for obtaining exceptions is irksome and in my opinion needlessly involved. Appeals for variation cannot be granted by the Division of Industrial Hygiene, even though it concurs, but must be carried through to the Board of Standards and Appeals. With a performance code, the designated standard can be achieved by any one of a number of methods (with a few limited exclusions such as precluding the use of respirators where ventilation or confinement should be applied).

In the successful development of this program the cooperation of governmental and private industrial hygiene forces is essential. Industry cannot, and an enlightened industry will not, contend that the control of working conditions is solely their prerogative. Neither can the governmental hygienist insist that the setting and enforcing of standards or permissive limits is solely his responsibility. The job is sufficiently big for all of those concerned, and even with their maximum effort, will lag far behind in effective accomplishment. We must persuade the ultraconservative that action must be taken even when the facts are not quite as complete as we would like them.

We must suppress the uncritical enthusiasm of those who believe that a magic exists in numbers, even though tenuously arrived at. The need for information is very real and much can be accomplished by intelligent and positive cooperation.

Ventilation of Open Tanks

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THE MOST effective and efficient tank hood is an enclosure consisting of a top and two or three sides with all or part of the other side or sides open for access to the tank (Figs. 1, 2 and 3). The simplest form of tank hood is an overhead overhanging canopy. Each of the four sides of a canopy is generally open to air flow if it is not

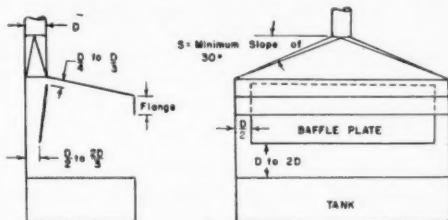


Fig. 1.
Enclosing hood

immediately adjacent to a building wall (Fig. 4). Hoods with three closed sides are relatively immune to the adverse effects of room cross drafts. Those with two, one, or no closed sides are progressively more subject to these effects and therefore require proportionately higher minimum control velocities.

The most common objection to enclosing hoods is that they impede access to the tank. This objection sometimes also applies to canopy hoods. In addition, canopy hoods may require the worker to breathe contaminated air rising from the tank to the hood and are most extravagant in their ventilation require-

ment. These latter objections may occasionally be overcome when a canopy hood can be lowered or swung over a tank close to its surface and has to be removed from these positions at only infrequent intervals (Fig. 4).

Where the above objections preclude the use of enclosing or canopy hoods, lateral exhaust (Fig. 5, 6, 7 and 8) must be employed. Its distinguishing characteristics are that all or a large part of the tank has no hood vertically above it and that these portions are ventilated horizontally by adjacent hood openings under suction.

In the case of enclosing and canopy hoods, control velocity is the velocity across a hood opening. However, in the case of lateral exhaust, this concept requires revision to the following definition: Velocity towards the hood or hoods measured at the point at the top of the tank most remote from the hood opening or openings.

Cylinder Analogy for Lateral Tank Exhaust

BASICALLY, all lateral tank exhaust conforms to the cylinder analogy which considers the hood opening to be the axis

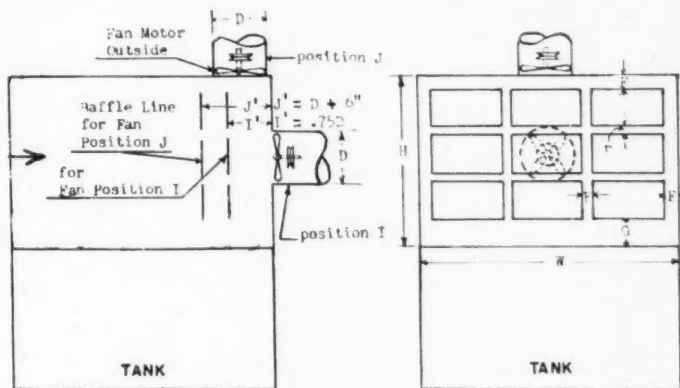


Fig. 2.
Enclosing hood. Spacing of Baffles: Depending on individual design and size of booth, spacing should be as follows: $E=3''$ to $6''$; $F=3''$ to $8''$; $G=8''$ to $24''$

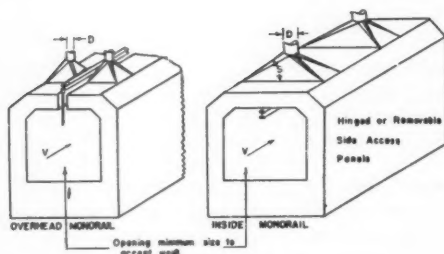


Fig. 3.
Enclosing hood

of a cylinder having a radius equal to the distance from the hood to the point at the top of the tank where control velocity is required (i.e., most remote from the hood) and having a surface area equal to that portion of the cylinder through which air can flow (i.e., eliminating the portion intercepted by the tank, the walls and the floor). The surface area of that arc of cylinder through which air can flow times the control velocity gives a first approximation of the required ventilation. Fig. 9 shows that the expression for this product has the general form $K\pi WL$ with K having values from a half to one and a half for the hood types illustrated, and that the required ventilation rate has the general form $K\pi VWL$, where V is control velocity. Since WL is equal to tank surface area, it is theoretically proper to specify ventilation rates as CFM per square foot of tank surface area. According to the cylinder analogy, the W/L ratio has no significant effect on ventilation. However, from experimental and practical data available, the W/L ratio is known to be an important variable because when a long, narrow tank has a

hood along its long side, less air is required for control than when the hood is on the narrow side.

The explanation is that the cylinder analogy assumes the hood to act as a line source of infinite length. However, in an actual hood of relatively short length, the cylinder analogy breaks down near both hood ends which must of necessity more closely approximate point suction sources whose ventilation rate equation has the general form $K\pi VW^2$ or $K\pi VL^2$, depending on whether the hood is on the long or the short side of the tank, respectively. Because of these end effects and because, as constructed, hoods are not as effective behind themselves as in the direction of their opening, actual values of K in the expression $K\pi VWL$ are lower than predicted by analogy and are variable with the W/L ratio of the tank.

Factors in Lateral Exhaust Hood Design

EXPERIENCE indicates that it is undesirable to ventilate from hoods along the short sides of a rectangular tank.

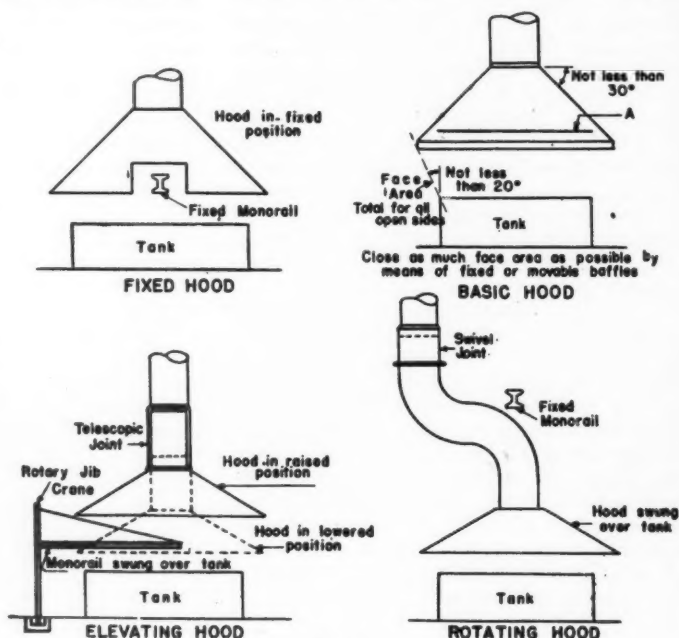


Fig. 4.
Canopy hoods

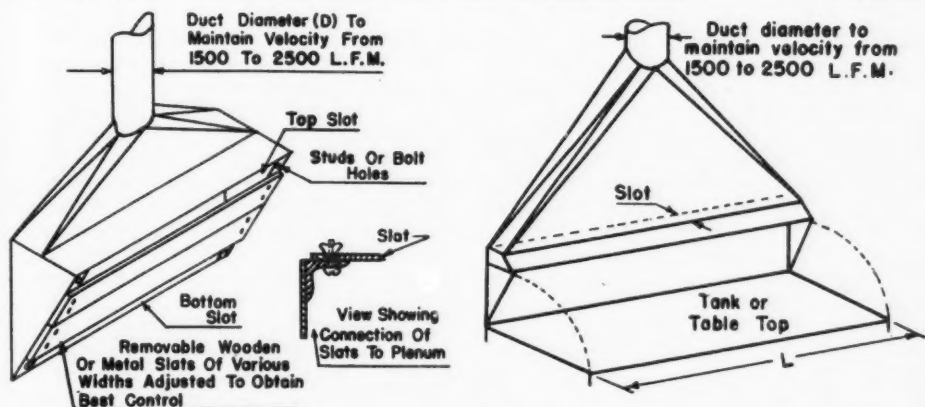


Fig. 5.

Lateral hood. Note: Maximum width, $W=4$ feet; Minimum ratio, length to width, L/W , 2 to 1; maximum length of transition piece, 4 feet; (Use more than one for larger hoods)

Such ventilation should not be attempted when the W/L ratio exceeds 2.

The closer a lateral hood approaches an enclosing hood in appearance and design, the more efficient it becomes. Thus as much tank overhang and side baffling as possible should be used, particularly on hot tanks.

On such tanks an elevated overhanging hood takes advantage of the normal upward vector of convection currents over the tank. Figs. 5 and 6 show lateral hoods.

Center Hoods

It is sometimes possible to use a hood that is a cross between a canopy hood and a lateral hood. These are canopy-like hoods covering less than the full area of the tank and dropped close to the tank surface (Fig. 10).

Since it is difficult to work under the hood, work must be introduced into and removed from the tank in the annular

space between the hood and the tank wall. The ventilation across this space may be designed either to maintain control velocity across the open area between hood and tank by figuring the hood as a canopy or to maintain control velocity at the tank wall by figuring the hood as a lateral one.

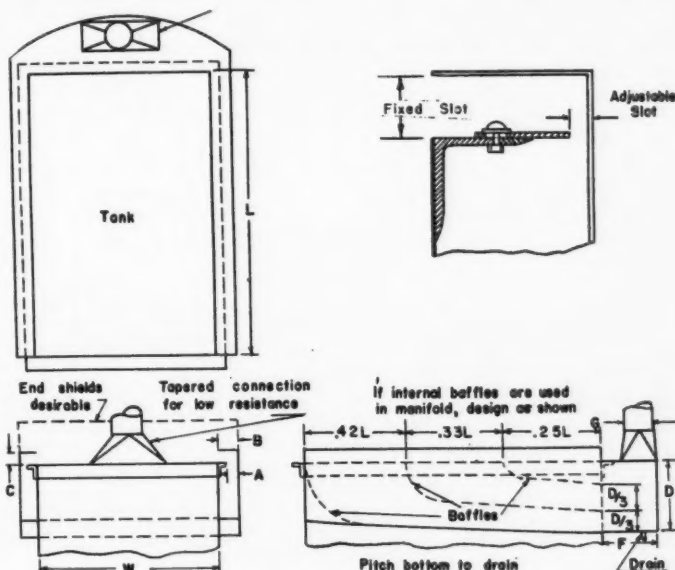


Fig. 6.
Lateral hood

Air Distribution

AIR may be conserved in all hood types by minimizing point to point velocity variation across their frontal openings. To illustrate the extent of saving possible, assume an enclosing hood with three closed sides having an inward velocity at one end of the tank half of that at the other end. Maintaining control velocity at the former results in twice control velocity at the latter. This requires an average velocity and ventilation rate 50% greater than would have been required had there been substantially no velocity variation from end to end or from top to bottom of the hood opening.

The most common method for obtaining uniformity of air distribution is to construct the hood so that the suction connection from the hood to the exhaust fan is taken from a plenum chamber or manifold of large enough cross-sectional area in the direction of air flow so that the air velocity through it is low in relation to that past a restriction of area interposed somewhere between the plenum and the atmosphere being exhausted.

The pressure drop of the low velocity air flowing through the plenum or manifold is that of the frictional resistance of its walls and is consequently low. The pressure drop of the high velocity air past the restriction of area is that of air flowing through an

orifice, usually having parallel edges, and is consequently high both because velocity pressure is higher than that of the low velocity air and because the pressure drop in flowing through the orifice may be as high as several velocity heads. All air flowing into the plenum must pass through the restricted area, but all air flowing past the restricted area does not have to pass through the same length of plenum. If the pressure drop through a length of manifold or plenum is p_m and that through the restricted area is p_s , the pressure drop operating to cause flow through the length of restricted area nearest the exhausted end of the manifold is $p_s - p_m$. The flow through the two unit lengths will be $Q_1 = C_1 A_1 \sqrt{p_s}$ and $Q_2 = C_2 A_2 \sqrt{p_s - p_m}$ respectively, and the ratio of flows will be $\frac{Q_2}{Q_1} = \frac{C_2 A_2 \sqrt{p_s - p_m}}{C_1 A_1 \sqrt{p_s}}$

However when the restriction or slot is unit-length, $C_1 = C_2$ and, per unit length, $A_1 = A_2$. Therefore $\frac{Q_2}{Q_1} = \sqrt{\frac{p_s - p_m}{p_s}} = \sqrt{1 - \left(\frac{p_m}{p_s}\right)}$ and since $\frac{Q_2}{Q_1} = \frac{Q_1 - (Q_1 - Q_2)}{Q_1}$, then it follows that:

$$1 - \left(\frac{Q_1 - Q_2}{Q_1}\right) = \sqrt{1 - \left(\frac{p_m}{p_s}\right)}$$

The relationship between $\frac{(Q_1 - Q_2)}{Q_1}$ and $\frac{(p_m)}{p_s}$ is as follows in Table I.

$\left(\frac{p_m}{p_s}\right)$ is as follows in Table I.

Slot Velocity

THE manifold or plenum pressure drop (p_m) can be estimated from the size, shape, velocity and flow pattern of the manifold. It must be multiplied by the appropriate number from the right hand column of Table I to obtain the required restriction or slot

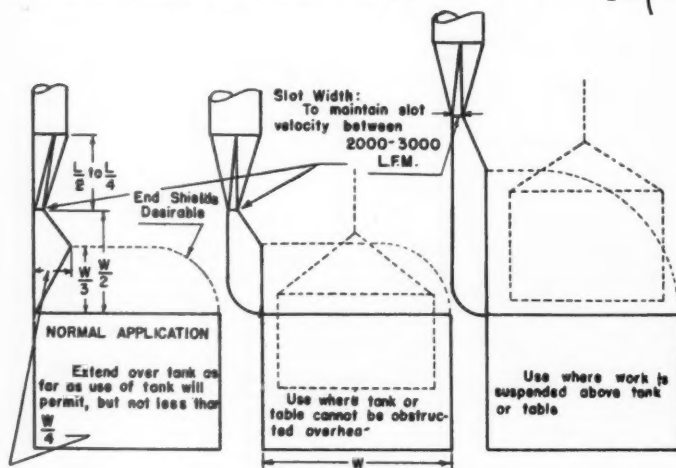


Fig. 7.
Rear hood

TABLE I.
RELATION OF LONGITUDINAL AIR DISTRIBUTION
TO MANIFOLD PRESSURE DROP-SLOT PRESSURE
DROP RATIO

$\left(\frac{Q_1 - Q_2}{Q_1}\right)$	$1 - \left(\frac{Q_1 - Q_2}{Q_1}\right)$	$1 - \left(\frac{p_m}{p_s}\right)$	$\frac{p_m}{p_s}$	$\frac{p_s}{p_m}$ to nearest whole number
.25	.75	.56	.44	2
.20	.80	.64	.36	3
.15	.85	.73	.27	4
.10	.90	.81	.19	5
.05	.95	.90	.10	10

pressure drop. Since for each form of restriction or slot the number (N) of velocity heads lost when air flows through is known, and since one velocity head = $\left(\frac{V}{4005}\right)^2$ where V is in FPM, the required velocity through the slot may be computed as follows:

$$\text{Required slot velocity} = 4005 \sqrt{\frac{p_m \times (p_s/p_m)}{N}}$$

Example: For example assume that a 2 ft. x 12 ft. tank using lateral exhaust at 100 FPM control velocity, having one of its long sides effectively baffled and having hoods with slots along both long sides requires 1500 CFM per hood. A 6 in. x 22 in. manifold, which has a pressure loss equivalent to a 12 in. round duct, would have a velocity at the exhaust end of 1630 FPM in the rectangular duct and 1900 FPM in the equivalent round duct. At the center of the duct these velocities would be halved and at the closed duct end they would approach zero. The effective average velocity, since duct friction increases with the square of velocity, occurs at 2/3 the manifold length from the closed toward the open end, i.e., 1270 FPM in the equivalent round duct. The duct friction for a velocity of 1270 FPM in 12 ft. of 12 in. round duct (considered medium rough to compensate for lack of knowledge of flow

pattern) is .048 in. Therefore $p_m = .048$ in. If a flow variation of not over 5% is required the value of $\left(\frac{Q_1 - Q_2}{Q_1}\right)$ in Table I is

$$.05 \text{ and the corresponding value of } p_s/p_m \text{ is } 10. \text{ If a slot having 1.75 velocity heads loss (i.e., } N = 1.75) \text{ is used, substituting in the formula yields: Required slot velocity} = 4005 \sqrt{\frac{.048 \times 10}{1.75}} = 2100 \text{ FPM.}$$

Once the required slot velocity is known, the slot area for any required air flow is easily obtained. Where one dimension of area (i.e., slot length) is fixed by the size of the tank, the size of the other dimension (in this case slot height) is likewise obtainable by direct computation. Any decrease in that dimension needlessly increases the non-recoverable overall pressure loss of the hood and should, therefore, be avoided. Any increase will result in greater non-uniformity of air distribution across the hood face than that specified.

Slot Location

IN CERTAIN hood types, such as Figs. 5 and 6, some confusion exists as to which restriction of area constitutes the slot. These figures show both a hood face slot and a hood throat slot. Where the throat slot is narrower than the face slot, the throat slot acts as the effective means for air distribution and the face opening should be made as large as possible. Conversely where the face slot is the narrower of the

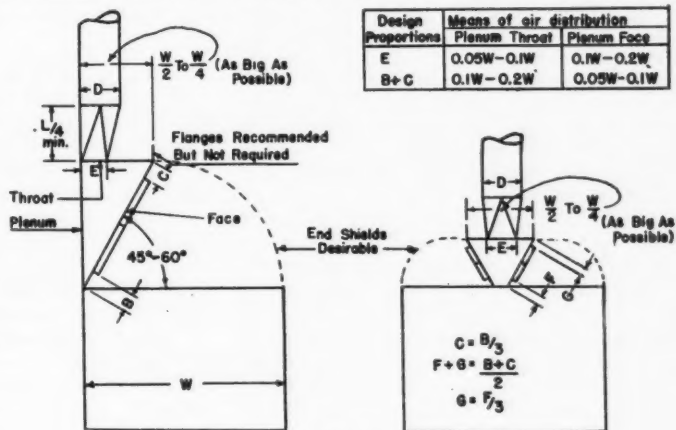


Fig. 8.
Slant hood

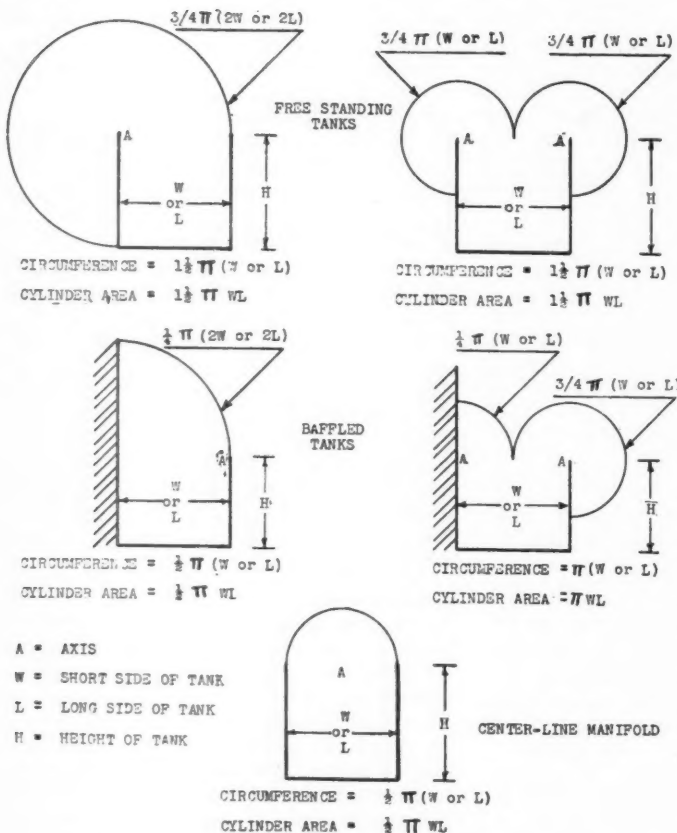


Fig. 9.
 Cylinder Analogy for tank ventilation. Cross sections through control velocity cylinders on tanks

two, the throat slot is superfluous and should be omitted. Making both slots almost the same size is poor design because it doubles the back pressure of the hood without any improvement in longitudinal air distribution.

Low Velocity and Tapered Manifolds

WHERE a large plenum or manifold can be used with a correspondingly low plenum pressure drop, a low slot or restriction velocity and a hood having a low over-all pressure drop and power demand results. In fact, slotted lateral tank hoods with low enough system pressure loss to allow their use with propeller type fans have been designed. There is, therefore, no fixed

minimum slot velocity, even though with the small manifolds generally required for convenient access to tanks laterally ventilated from both long sides, the commonly used minimum of 2000 FPM slot velocity is a safe design figure.

Since the larger the manifold cross-section, the better the distribution from any given size of slot, there is no improvement in distribution to be gained by building a manifold shallow at the closed end with its area (i.e., depth) increasing uniformly toward its exhausted end. The principal advantage of such designs is that any tank liquid splashed into or condensed in the manifold can drain to the low point of the manifold where a drain pipe should be installed. Therefore, a moderate bottom pitch toward the ex-

hausted end of the manifold is desirable, but a taper extreme enough to increase plenum pressure drop should be avoided. In this category are tapers designed on a constant velocity basis. Because small cross-sections have a higher pressure drop per unit length than large ones, such tapers tend to starve the far end of the manifold.

Tapered and Multiple Slots

SOME designers have advocated the use of tapered slots in either rectangular or tapered manifolds. By decreasing slot height as the exhausted end of the manifold is approached, a design could be achieved in which the sum of slot loss plus manifold loss is the same from all unit

lengths of the manifold. The methods of computation already outlined can readily be used to make a foot by foot analysis of any given manifold to determine the slot height at each foot necessary to achieve this balance. However, such precision of design is of doubtful value since the recommended designs of slots all provide for final field adjustment of the slot opening. Where the slot is formed by a metal strip bolted through elongated holes to an angle, a tapered slot can be achieved by adjustment of the holes with respect to the bolts before finally tightening them. This is true whether the slot is inside the manifold or on the face of the hood. In the latter case, it is not uncommon to use two or three parallel slots, the total area of which is used as the basis for design.

Distributing Plates in Enclosing Hoods

AN ENCLOSING type hood equipped with internal distributing plates or baffles can operate at a low enough plenum velocity to keep the manifold pressure drop under 0.003 in. with a corresponding design velocity of 500 FPM through the spaces between such plates. The relationship between hood velocity and percent of hood cross-section area obstructed by uniformly spaced baffle or distributing plates to achieve this slot velocity is as follows:

Hood Velocity FPM	% Area Required to be Obstructed to Obtain Uniform Face Distribution in a Shallow Hood or Booth
50	90%
75	85%
100	80%
150	70%
250	50%

A well-tapered canopy hood with an axial exhaust outlet equidistant from all four sides should need no internal baffling to produce uniform air flow through the sides in a draft-free room. However where the hood taper is shallow, where the exhaust outlet is eccentric to the hood axis or where room drafts are present, it is sometimes desirable to add a distributing plate or baffle in the location shown in Fig. 4. A plate having an area of from one half to three-quarters the area of the plane of the hood at which it is located should suffice to maintain an adequate slot velocity between the edges of the plate and the walls

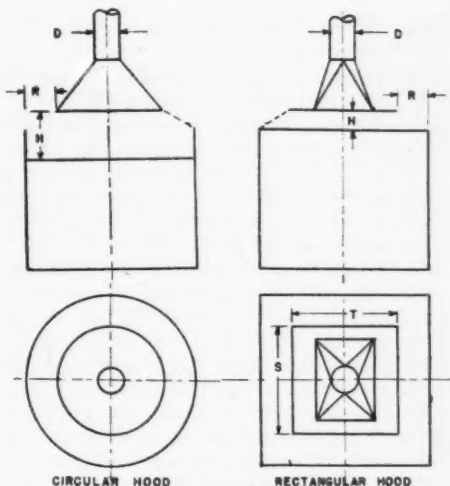


Fig. 10.
Center hoods

of the hood. This is so because the velocity at this plane without the plate in place is from two to four times control velocity or of the order of magnitude of from 300 to 500 FPM.

Vanes and Tapers

METHODS other than the use of slots or distributing plates for obtaining uniform air distribution across hood faces include the use of splitter vanes (Fig. 6), tapered connections (Fig. 1), and deep enclosures. Vanes have very limited application because they are difficult to design, construct and maintain. Tapers are subject to space limitations. Where adequate space is available for a low angle taper from suction pipe to hood, distribution may be obtained at the lowest possible pressure drop. Tapered connections of higher than optimum taper angle are sometimes used in connection with hood face or throat restrictions. In these constructions the tapered connection acts as the plenum and some quite satisfactory designs result. Lastly, if an enclosing type hood with its suction connection at the back is deep enough in the direction of airflow (i.e., at least as deep as the tank dimension perpendicular to the direction of air flow) the hood will act as a duct and yield reasonably uniform face velocity without the use of slots, baffles, vanes or tapers.

Classification of Operations and Selection of Control Velocity

THE choice of control velocity is one of the more difficult steps in the design process. The Proposed American Standard Code for Ventilation and Safe Operation of Open Surface Tanks includes a scheme for classifying open tank operations in such a manner that a reasonable control velocity may be selected for each.

In the proposed classification operations are divided into 12 ventilation classes, numbered A-1 to C-4, inclusive, in which the letter symbol (A, B or C) is the measure of necessity for ventilation. The number symbol portion of the classification (1, 2, 3 or 4) represents primarily the difficulty of ventilation, although it also serves as a measure of necessity of ventilating steam.

The letter portion of the symbol representing severity of the hazard has been designated "Hazard Potential," and is determined by the M.A.C. and the open cup flash point of the substance in the tank or the gas, vapor or mist produced from it. The M.A.C. (termed Hygienic Standard in the rules) measures toxicity, and the flash point measures explosion hazard. Table II states the limits of these measures for the three Hazard Potential Classes.

TABLE II.*
DETERMINATION OF HAZARD POTENTIAL

Hazard Potential	Hygienic Standards		
	Gas or Vapor	Mist	Flash Point
A	0—100 ppm	0—100 $\mu\text{g}/\text{cu m}$	under 100 F
B	101—500 ppm	101—500 $\mu\text{g}/\text{cu m}$	100—200 F
C	over 500 ppm	over 500 $\mu\text{g}/\text{cu m}$	over 200 F

(μg = micrograms)
*Adapted from table in Proposed American Standard Code for Ventilation and Safe Operation of Open Surface Tanks. (See acknowledgement at end of paper.)

The number portion of the symbol representing relative capacity for gas, vapor or mist production and relative energy of such production has been designated "Rate" and

*A. K. DOOLITTLE: Industrial and Engineering Chemistry 27:1169. Time for 100% evaporation: Fast: 0.3 hrs.; Medium: 3-12 hrs.; Slow: 12-50 hrs.; Nil: more than 50 hrs.

**Examples: High—Bright Dip (Nitric Acid) of Brass and Bronze; Chrome Plating; Anodizing Aluminum; Stripping Galvanizing in Acid Baths; Satin Finish of Aluminum. Medium—Pickling of Steel; Alkaline Cleaning of Aluminum (Cold); Electrolytic Strike; Battery Plate Forming. Low—Alkaline Cyanide Plating of Zinc; Phosphoric Acid Dipping of Steel; Tin Plating from Stannate Solution; Phosphate Treatment of Metal.

TABLE III.*
DETERMINATION OF RATE OF GAS, VAPOR, OR MIST EVOLUTION

Rate	Liquid Temp., F	Degrees Below Boiling Point	Relative Evaporation	Gassing
1	over 200	0—20	Fast	High
2	150—200	21—50	Medium	Medium
3	94—149	51—100	Slow	Low
4	Under 94	Over 100	Nil	Nil

*Adapted from table in Proposed American Standard Code for Ventilation and Safe Operation of Open Surface Tanks (See acknowledgement at end of paper).

is determined by (a) the temperature of the liquid in the tank in degrees Fahrenheit; (b) the number of degrees Fahrenheit that this temperature is below the boiling point of the liquid in degrees Fahrenheit; (c) the relative evaporation of the liquid in still air at room temperature in an arbitrary scale (fast, medium, slow or nil)* and (d) the extent that the tank gases or produces mist, also in an arbitrary scale (high, medium, low or nil).** Table III gives the limits of these measures for the four Rate classes.

Vapor degreasers do not fit directly into this classification scheme since they are fitted with integral control means in the form of internal condensers or vapor level thermostats. Since vapor evolution from such tanks is caused primarily by abnormalities of operation, it is suggested that in Table III, the effective rate of evolution be taken as 4 when operating procedure is excellent; as 3 when it is average; and as 2 or 1 when it is poor, the number depending upon observed conditions.

Examples of Classification Scheme

WHERE a substance or operation falls into more than one class on different individual criteria, the letter for Hazard Potential indicating greater hazard (A rather than B; B rather than C) and the lowest indicated number for Rate should be used. Some examples of determination of class are:

- (a) Boiling Water.....Class C-1
- (b) Methyl Alcohol at 68°F. . . " A-1
- (c) Nickel Plating at 140°F. . . " C-3
- (d) Chrome Plating at 110°F. " A-1
- (e) Caustic Soda Treatment of Aluminum—68°F. " B-2
- (f) Trichlorethylene Vapor Degreaser—Excellent Operating Procedure " B-4

TABLE IV*
MINIMUM CONTROL VELOCITY (FT. PER MIN.—
FPM) FOR UNDISTURBED LOCATIONS

Class	Enclosing Hood		Lateral Exhaust	Canopy Hood	
	One Open Side	Two Open Sides		Three Open Sides	Four Open Sides
A-1, A-2 and B-1	75	100	100	125	175
A-3, B-2 and C-1	65	90	75	100	150
B-3 and C-2	50	75	50	75	125
A-4, B-4, C-3 and C-4	Adequate general room ventilation required				

*Adapted from table in Proposed American Standard Code for Ventilation and Safe Operation of Open Surface Tanks (See acknowledgement at end of paper).

TABLE V.*
SUGGESTED VELOCITIES TO COMPENSATE FOR
ROOM CROSS DRAFTS AT TANK LEVEL

Draft Definition	Add to Minimum Control Velocity for Undisturbed Location FPM
Slight	25
Moderate	50
Strong (a)	100
Very Strong (a)	200

(a) It is preferable to use baffles to overcome strong drafts rather than use additional control velocity.

*Adapted from table in Proposed American Standard Code for Ventilation and Safe Operation of Open Surface Tanks (See acknowledgement at end of paper).

Once an operation has been given a class designation, the minimum control velocity required may be read from Table IV.

Correction of Control Velocity For Cross Drafts

IT WILL be noted that the values in this table are for undisturbed locations and must therefore be increased to compensate for room cross drafts, where such drafts cannot be overcome by the use of baffles or additional tank enclosure. When a visit to the actual or proposed tank location will allow a measurement of the direction and magnitude of the disturbance, the correction should be based upon the net adverse effect of the disturbance, that is, the extent that it operates in a direction counter to that of control velocity. Where the disturbance cannot be measured the corrections suggested in Table V can be used, subject to the same precaution that only their net effect need be added to the velocities of Table IV.

An example of such correction might be that of an operation classified A-1 and

using lateral exhaust. The minimum control velocity from Table IV is 100 FPM. If a cross draft measured at 50 FPM and operating to prevent effective functioning of the hood is present, the air quantity should be selected on a 150 FPM control velocity basis. However, should this moderate draft act to partially assist the operation of the hood, all or part of it could be neglected and the air flow computations made on a 100 or 125 FPM basis.

Other Correction of Control Velocity

WHERE the rate of release of gas, vapor or mist normal to an open tank operation is lowered by auxiliary means such as tank covers, foams, beads, chips or other materials floating on the tank surface,¹ by surface tension depressive agents² added to the liquid in the tank or any similar means, it may be possible to lower the required control velocity. Such lowering is inadvisable where there is doubt as to the continuity of action of the auxiliary control means, i.e., whether the bead or foam layer will at all times remain intact during operation and whether there will always be sufficient additive agent in the tank liquid.

TABLE VI.*
MINIMUM VENTILATION RATE IN CUBIC FEET
OF AIR PER MINUTE PER SQUARE FOOT OF
TANK AREA FOR LATERAL EXHAUST

Required Minimum Control Velocity FPM	Hood along one side or two parallel sides of tank, one hood being against a wall or baffle as high as the tank is wide. Also for a manifold along tank center line					
	CFM/sq. ft. to maintain FPM at following $\left(\frac{\text{Tank width}-W}{\text{Tank length}-L}\right)$ ratios.					
	0—0.09	0.1—0.24	0.25—0.49	0.5—0.99	1.0—2.0	
50	50	60	75	90	100	
75	75	90	110	130	150	
100	100	125	150	175	200	
150	150	190	225	260	300	

Hood along one side or two parallel sides of free standing tank not against wall or baffle					
50	75	90	100	110	125
75	110	130	150	170	190
100	150	175	200	225	250
150	225	260	300	340	375

Tank Width (W) means the effective width over which the hood must pull air to operate (i.e., where the hood face is set back from the edge of the tank, this set back must be added in measuring tank width).

*Adapted from table in Proposed American Standard Code for Ventilation and Safe Operation of Open Surface Tanks (See acknowledgement at end of paper).

EXAMPLE OF USE OF TABLE VI
 Tank—12 ft. x 2 ft. (Area—24 sq. ft.)
 Required minimum Control Velocity—100 FPM

Tank Location	Hood Location	W/L	CFM per Sq. Ft. from Table VI	Total CFM Required	CFM Required per Hood
Free Standing	Along one long side	0.17	175	4200	4200
Free Standing	Along both long sides	0.17	175	4200	2100
Free Standing	Along long centerline	0.08	100	2400	2400
One side against wall or baffle	Along the baffled long side	0.17	125	3000	3000
Free Standing	Along both long sides	0.17	125	3000	1500
	Along one or both short sides	6.0	Ventilation Impracticable		
Free Standing	Along short centerline	3.0	Ventilation Impracticable		

Where dilution ventilation calculations show that effective control by dilution³ may be achieved at lower than the specified velocity required for effective local ventilation, it is reasonable to design for the lowest air quantity that will protect workmen.

Control Air Quantity for Lateral Exhaust

ANOTHER feature of the Proposed American Standard Code for Open Surface Tanks is the scheme for selection of minimum ventilation rate for lateral exhaust for different W/L ratios and control velocities (Table VI). The use of this table is best explained by the example which accompanies the table.

In all forms of lateral ventilation, hoods should be flanged as much as possible even where the flanges are not big enough to approximate the condition of an adjacent wall. Where such flanging is employed, control air quantities intermediate between those of the two tables of Table VI can be used.

Push-Pull and Supplied Air Systems

NO DISCUSSION of tank ventilation would be complete without at least mentioning those designs which supply air through ducts or pipes to the tank. They include:

(a) Supplying unheated outdoor air at low supply velocity for the purpose of conserving heated room air during cold weather.

(b) Supplying compressed air at high pressure to nozzles directed at the exhaust opening to project and entrain air into the hood opening.

(c) Supplying room air or unheated air at medium pressures for the same purpose and

(d) Recirculating a portion of the air exhausted from the tank through nozzles for the same purpose.

In general, caution must be observed with supplied air or push-pull systems lest the air jet blow air contaminants into the workroom rather than exhaust them. Their use is therefore limited to applications where the act of introducing work to the tank is either infrequent, or so conducted that it does not obstruct the path of the jet. They show power savings only where full advantage is taken of the small included angle of a jet compared to the wide included angle of a suction hood so as to allow a large reduction in design control velocity and total air flow of the suction hood. Where the resulting reduction in suction CFM times its total negative static pressure is greater than the jet CFM times its total positive static pressure, power savings will be achieved, otherwise the only savings possible are winter heat savings which may or may not be sufficient to justify a push-pull system. It is claimed that push-pull systems are particularly efficacious on very wide tanks. The author has had no experience with such applications and can neither affirm nor deny these claims.

Summary

1. Characteristics of enclosing, canopy and lateral type tank hoods are discussed.

2. Means for obtaining uniform air distribution across the face of these hoods are outlined, and a method for calculating slot velocity is developed.

3. The schemes for classifying open tank operations and selecting minimum control velocity and ventilation rates developed for the Proposed American Standard Code for

Ventilation and Safe Operation of Open Surface Tanks are explained.

(80 Centre Street, New York 13, N. Y.)

ACKNOWLEDGEMENT: The Proposed American Standard Code for Ventilation and Safe Operation of Open Surface Tanks (Z-9. 1/46) is a Private Committee Document, not for publication, and is therefore not obtainable from the American Standards Association. Should this proposed code be adopted, it will be published as a Standard and will be obtainable as such from the American Standards Association, 70 East 45th Street, New York 17, N. Y. The Subcommittee which prepared the draft of this proposed standard consisted of

A. C. STERN, Chairman, S. E. BARR, E. R. BOWERMAN, A. D. BRANDT, H. F. BRUSH, M. B. DIGGIN, W. B. HARRIS, N. V. HENDRICKS, M. G. KERSHAW, J. W. MCWILLIAMS, B. POSTMAN, L. SILVERMAN, A. W. SMART, O. G. STAM, G. E. WALLIN and W. N. WITHERIDGE.

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1. STERN, ARTHUR C., BENJAMIN, LAWRENCE P., and GOLDBERG, HARRY: The Use of Plastic Beads on Chrome Plating Tanks, N. Y. State Department of Labor, *Monthly Review*, 28:1 (January) 1949, 1-4.
2. SILVERMAN, LESLIE, and THOMSON, ROBERT M.: Mist Control with Addition Agents in Chrome Plating. *J. Indust. Hyg. & Tox.*, 30:5 (September) 1948, 303-306.
3. HEMMON, W. C. L.: Air Dilution in Industrial Ventilating. *Heating & Ventilating* (March) 1941, 71-2.

Symposium on Tuberculosis in Industry

INDUSTRIAL PHASES of tuberculosis were discussed on September 25, 1950, at a Symposium conducted in Milwaukee by the International Association of Industrial Accident Boards and Commissions. The general theme of the Symposium was "When may Tuberculosis be Considered an Occupational Disease?"

In discussing "The Influence of Physical Factors Such as Heat, Humidity, and Physical Effort on the Course of Tuberculosis," A. G. Kammer, M.D., Head of Department of Occupational Health, University of Pittsburgh, presented the results of a study of a large number of employees and applicants for work at a steel plant. His conclusions were that hard physical work in hot environments did not predispose workers to pulmonary tuberculosis.

WM. G. CHILDRESS, M.D., Instructor in Medicine, Columbia University, discussed "Tuberculosis in Sanatorium and Hospital Personnel." He expressed the opinion that nurses and general employees of tuberculosis hospitals who have a negative x-ray on employment and develop clinical tuberculosis should be considered as having a compensable case whether their initial tuberculin tests were negative or positive. Where the pre-employment x-ray shows healed tuberculosis and activity occurs after employment, there is usually an effort to obtain compensation but Dr. CHILDRESS knew of only one claim in this category being allowed.

In one hospital with which Dr. Childress was associated, there had been 3.5 tuberculosis claims per year over the period 1932 to 1939; a BCG vaccination program was started in 1939 among those who were tuberculin negative and since that time not a single case of tuberculosis has developed among this group. Dr. Childress made the conservative comment that he was dealing with too small a group to justify drawing of any broad conclusion on the basis of this experience.

"The Influence of Dust Inhalation on Pulmonary Tuberculosis" was discussed by O. A. SANDER, M.D., Associate in Medicine, Marquette University School of Medicine, Milwaukee. DR. SANDER observed there is no evidence in this country that tuberculosis is activated by any dust other than that containing free silica. He further stated that, before tuberculosis is activated by the effect of dust, silicosis must have been developed on the lung tissue of the exposed person—not merely that the person was exposed to silica dust. He feels that more recent evidence indicates that there is only a very slightly greater probability of development of tuberculosis by the silicotic than by the non-silicotic person. Among a group of 500 workers with simple silicosis whom DR. SANDER has been following, less than a dozen have developed tuberculosis over the past 18 years. Of this group, there has not been a single case in the last five years of a simple silicosis going over to silico-tuberculosis.

DAVID T. SMITH, M.D., President of the National Tuberculosis Association, presented a valuable discussion on "The Rehabilitation of Ex-Patients and Its Implications," a subject of much importance to industry in placement of workers whose tuberculosis has been arrested.

John F. McMahon
(1903-1950)

JOHAN F. McMAHON, Managing Director at the Industrial Hygiene Foundation, died suddenly in his office at Mellon Institute, Pittsburgh, Pennsylvania on September 15, 1950. He had been an administrative fellow of the Institute for 14 years, and directed the Foundation since 1942.

Born in South Waverly, Pennsylvania John McMahon received his early education at Sayre, Pennsylvania. He was graduated from Notre Dame University with a Bachelor of Arts Degree in 1928. From 1929 to 1936 he served in various capacities in newspaper and public relations work.

At the beginning of his professional career he served as a reporter on the *New York Sun*. Later he spent two years in public relations work for Columbia University, the American Chemical Society and other technical organizations. He then became night editor for the Associated Press in Pittsburgh, and after four years became associated with Mellon Institute. His early work at the Institute was concerned with public relations.

When John McMahon became interested in industrial hygiene, the profession had not received universal recognition as industry was not fully convinced of its importance. His work toward the advancement of industrial hygiene has in no small part contributed to the high regard the profession now enjoys. His aptitude for



writing about technical subjects in a non-technical manner, forcefully brought the subject of industrial health before plant executives, professional groups and the public.

In his eight years as Managing Director, the Industrial Hygiene Foundation grew steadily until now it has more than 200 member companies; it has commanded the respect of industry, labor and scientists; and its members continually depend on its services, advice and guidance in industrial

health problems.

John McMahon had a great capacity for developing interesting and different programs for the Foundation's Annual Meetings which were valuable contributions to both the scientific and administrative phases of industrial health. He had a faculty for apt epigrams which added zest to the meetings. His warm friendship for people with whom he associated was only one of the many traits which attracted people to him.

He had the ability to attract a technical staff of high caliber which contributed generously to the scientific literature during his years as Foundation Director.

His passing will be keenly felt. The Institute, the Foundation's staff and all who knew him will miss his friendly smile, his sound council and his leadership. Above all, industrial hygiene will miss a true friend.

American Industrial Hygiene Association

— News of Local Sections —

Chicago Section

THE ANNUAL MEETING of the Chicago Section was held Wednesday, June 7, 1950. The subject "Industrial Hygiene and the Manufacture of Brake Lining" was presented by Frank E. Tayler, Chief Engineer, Brakeblok Division, American Brake Shoe Company, Detroit, Michigan.

The following officers were installed for the 1950-51 year: L. E. HAMLIN, M.D., American Brake Shoe Company, President; ELGIN D. SALLEE, American Can Company, President-Elect; and HOWARD N. SCHULZ, Abbott Laboratories, Secretary-Treasurer. WILLIAM T. MCCORMICK, GEORGE F. NUERNBERGER, PAUL LANGE and DR. EUGENE WALSH were elected to the Board of Directors to serve for a period of three years.

The first meeting of the Chicago Section for the fall of 1950 will be Wednesday, September 6, 1950.

Northern Ohio Section

THE ANNUAL MEETING of the Northeastern Ohio Section was held at the Cleveland Engineering Society Auditorium May 25, 1950. This was an all-day meeting which covered a discussion of the following subjects: "Practical Control of Metal Plating Health Hazards" by FRANK A. PATTY; "Lead Intoxication—Industrial and Otherwise" by MANFRED BOWDITCH; "Characteristics of Instruments Used for Measuring Radiation Hazards" by DUNCAN HOLADAY; "Ventilation Control of Industrial Health Hazards" by DR. ALLEN D. BRANDT; "Control of Radiant Heat" by W. G. HAZARD.

New officers to serve during the 1950-51 year are E. O. KUMLER, President; W. E. MCCORMICK, Vice-President; and K. A. KELSEN, Secretary-Treasurer.

Philadelphia Section

KENNETH R. DOREMUS, president of the Philadelphia Section during the 1949-50 year, has accepted a position as Industrial Hygiene Engineer, Eastern Department, Lumbermens Mutual Casualty Company. Mr. Doremus will have his headquarters in Philadelphia, Pennsylvania.

Rocky Mountain Section

THE ROCKY MOUNTAIN SECTION held its first meeting since organization on March 31 and April 1, 1950 at Santa Fe, New Mexico. The two-day meeting was attended by 37 members and guests, and the speakers included DR. THOMAS L. SHIPMAN, M. C. ROBBINS, FRANCIS SMITH and EDWIN C. HYATT. The movie, "Operations Crossroads," also was shown. The program for the afternoon of the second day of the meeting included tours of the Brochemistry Laboratory of the Atomic Energy project and the community of Los Alamos, New Mexico.

Southern California Section

ON JUNE 21, 1950, DR. JAMES H. STERNER discussed the subject "Dermatitis from Simple Chemical Compounds" at a meeting of the Southern California Section.

St. Louis Section

THE ST. LOUIS SECTION held its final meeting of the 1949-50 year May 22, 1950. This was a dinner meeting, at Hotel Melbourne, St. Louis, which was addressed by DR. CHARLES R. WILLIAMS on the subject, "The Industrial Hygienist and the Problem of Industrial Wastes." The next meeting of the section is planned for September, 1950.

Michigan Section

LEWIS B. CASE retired from the Industrial Hygiene Department of General Motors Research Laboratories on August 1, 1950. MR. CASE was a member of the Michigan Section and of the American Industrial Hygiene Association. His retirement marked the end of a 39-year career with General Motors.

Western New York Section

DURING JUNE, the Western New York Section held its first meeting since it was organized earlier in the year. The dinner meeting, which was held in Rochester, was attended by members and others in the Rochester area interested in industrial hygiene. The meeting attracted a

number of industrial hygiene people from Buffalo, Syracuse, Rome, and Corning.

Gulf Coast Regional Conference

THE THIRD ANNUAL Gulf Coast Regional Conference on Industrial Health will be held at the Rice Hotel, Houston, Texas, on October 12, 13 and 14, 1950. The conference is being sponsored by the Houston Chamber of Commerce in cooperation with The Texas State Health Department, Baylor University College of Medicine, Industrial Health Section of the American Medical Association, Gulf Coast Chapter of the American Society of Safety Engineers, American Association of Industrial Nurses, Industrial Hygiene Foundation of America, Texas Manufacturers Association and the Houston City Health Department. The preliminary program announcement includes such items as panels on "Teamwork in Industrial Health," "The Evaluation of the Degree of the Physically Handicapped Employee and His Employment," and a Symposium on Atmospheric Contamination and

Industrial Wastes; and discussion of "Atomic Energy and Its Significance," "The Texas Program of Vocational Rehabilitation for Disabled Persons" and "Mental Health and Industry." In addition, programs are being arranged to include sectional meetings for industrial nurses and engineers.

Board of Directors Meeting

AT A RECENT meeting of the Board of Directors, AIHA, two important changes were made with respect to requirements for membership in the association. The first change involves the recognition of scientific study and control of air pollution of industrial origin as a phase of industrial hygiene. The second added the requirement that a letter from one sponsor of each applicant for membership in the association accompany the application.

A new membership application form has been prepared and is now available upon request to the Executive Secretary.

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